This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

DANA'S
SERIES OF MINERALOGIES.

NEW "SYSTEM OF MINERALOGY."

Embodying the results of the last 24 years of active progress. Containing more than half more matter than the former edition and the page increased one-fifth in size. Not merely revised but entirely rewritten. Sixth edition, 1892..............................1197 pp., 1425 Cuts, $12 50

MANUAL OF MINERALOGY AND PETROGRAPHY.

Containing the Elements of the Science of Minerals and Rocks, for the use of the Practical Mineralogist and Geologist, and for Instruction in Schools and Colleges. By Jas. D. Dana, LL.D. Twelfth edition. Illustrated with numerous woodcuts....................12mo, cloth, 2 00

A TEXT-BOOK OF MINERALOGY.

With an Extended Treatise on Crystallography and Physical Mineralogy. By Edward Salisbury Dana, Professor of Physics and Curator of Mineralogy, Yale University. New edition, entirely rewritten and reset. With nearly 1000 figures and a colored plate........8vo, cloth, 4 00

CATALOGUE OF AMERICAN LOCALITIES OF MINERALS.

Reprinted from sixth edition of the System...8vo, cloth, 1 00

MINERALS, AND HOW TO STUDY THEM.

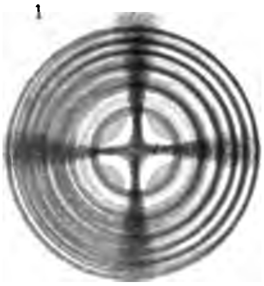
A book for beginners in Mineralogy. By Prof. E. S. Dana..12mo, cloth, 1 50

ALSO

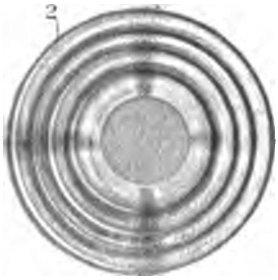
A TEXT-BOOK OF ELEMENTARY MECHANICS.

For the Use of Colleges and Schools. By Prof. E. S. Dana...12mo, cloth, 1 50

1

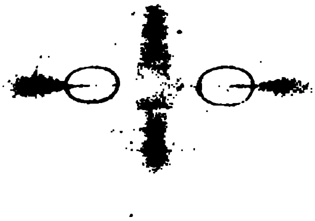


2

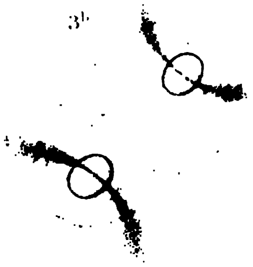


Orthorhombic, $\rho < v$

3ᵃ

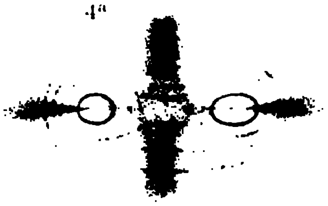


3ᵇ

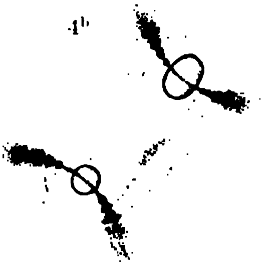


Monoclinic – Inclined Dispersion

4ᵃ

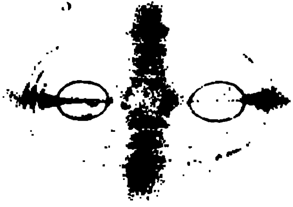


4ᵇ



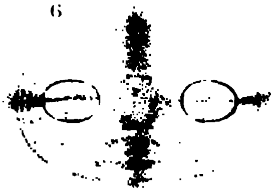
Horizontal Dispersion

5



Crossed Dispersion

6



A TEXT-BOOK

OF

MINERALOGY

WITH AN EXTENDED TREATISE ON

CRYSTALLOGRAPHY AND PHYSICAL MINERALOG

BY

EDWARD SALISBURY DANA

Professor of Physics and Curator of Mineralogy
Yale University

NEW EDITION, ENTIRELY REWRITTEN AND ENLARGED

With nearly 1000 Figures and a Colored Plate

NEW YORK
JOHN WILEY & SONS
LONDON: CHAPMAN & HALL, LIMITED
1899

554314

Copyright, 1898,
BY
EDWARD S. DANA.

ROBERT DRUMMOND, PRINTER, NEW YORK.

PREFACE.

THE remarkable advance in the Science of Mineralogy, during the that have elapsed since this Text-Book was first issued in 1877, has m necessary, in the preparation of a new edition, to rewrite the whole as w to add much new matter and many new illustrations.

The work being designed chiefly to meet the wants of class or p instruction, this object has at once determined the choice of topics disc the order and fullness of treatment and the method of presentation.

In the chapter on Crystallography, the different types of crystal form described under the now accepted thirty-two groups classed according to symmetry. The names given to these groups are based, so far as po upon the characteristic form of each, and are intended also to sugge terms formerly applied in accordance with the principles of hemihed The order adopted is that which alone seems suited to the demands o elementary student, the special and mathematically simple groups o isometric system being described first. Especial prominence is given t "normal group" under the successive systems, that is, to the group wh relatively of most common occurrence and which shows the highest deg symmetry. The methods of Miller are followed as regards the indices different forms and the mathematical calculations.

In the chapters on Physical and Chemical Mineralogy, the plan o former edition is retained of presenting somewhat fully the elementary ciples of the science upon which the mineral characters depend; this is ticularly true in the department of Optics. The effort has been made t the student the means of becoming practically familiar with all the m methods of investigation now commonly applied. Especial attenti therefore, given to the optical properties of crystals as revealed by the m scope. Further, frequent references are introduced to important pape the different subjects discussed, in order to direct the student's attenti the original literature.

The Descriptive part of the volume is essentially an abridgment o Sixth Edition of Dana's System of Mineralogy, prepared by the author (1 To this work (and future Appendices) the student is, therefore, referr fuller descriptions of the crystallographic and optical properties of speci analyses, lists of localities, etc.; also for the authorities for data here quoted. In certain directions, however, the work has been expanded when the interests of the student have seemed to demand it; for example, in the statement of the characters of the various isomorphous groups. Attention is also called to the paragraph headed "**Diff.**," in the description of each common species, in which are given the distinguishing characters, particularly those which serve to separate it from other species with which it might be easily confounded.

The list of American localities of minerals, which appeared as an Appendix in the earlier edition, has been omitted, since in its present expanded form it requires more space than could well be given to it; further, its reproduction here is unnecessary since it is accessible to all interested not only in the System of Mineralogy but also in separate form. A full topical Index has been added, besides the usual Index of Species.

The obligations of the present volume to well-known works of other authors—particularly to those of Groth and Rosenbusch—is too obvious to require special mention. The author must, however, express his gratitude to his colleague, Prof. L. V. Pirsson, who has given him material aid in the part of the work dealing with the optical properties of minerals as examined under the microscope. He is also indebted to Prof. S. L. Penfield of New Haven and to Prof. H. A. Miers of Cambridge, England, for various valuable suggestions.

NEW HAVEN, CONN., Aug. 1, 1898.

TABLE OF CONTENTS.

INTRODUCTION

PART I. CRYSTALLOGRAPHY.

GENERAL MORPHOLOGICAL RELATIONS OF CRYSTALS
GENERAL MATHEMATICAL RELATIONS OF CRYSTALS
I. ISOMETRIC SYSTEM
    1. Normal Group (1). Galena Type
    2. Pyritohedral Group (2). Pyrite Type
    3. Tetrahedral Group (3). Tetrahedrite Type
    4. Plagihedral Group (4). Cuprite Type
    5 Tetartohedral Group (5). Ullmannite Type
II. TETRAGONAL SYSTEM
    1. Normal Group (6). Zircon Type
    2. Hemimorphic Group (7)
    3. Pyramidal Group (8). Scheelite Type
    4. Pyramidal Hemimorphic Group (9). Wulfenite Type
    5. Sphenoidal Group (10). Chalcopyrite Type
    6. Trapezohedral Group (11)
    7. Tetartohedral Group (12)
III. HEXAGONAL SYSTEM
  A. Hexagonal Division
    1. Normal Group (13). Beryl Type
    2. Hemimorphic Group (14). Iodyrite Type
    3. Pyramidal Group (15). Apatite Type
    4. Pyramidal-Hemimorphic Group (16). Nephelite Type
    5. Trapezohedral Group (17)
  B. Trigonal or Rhombohedral Division
    1. Trigonotype Group (18)
    2. Rhombohedral Group (19). Calcite Type.
    3. Rhombohedral-Hemimorphic Group (20). Tourmaline Type
    4. Tri-rhombohedral Group (21). Phenacite Type
    5. Trapezohedral Group (22). Quartz Type.
    6, 7. Other Groups (23) (24)
    Mathematical Relations of the Hexagonal System
IV. ORTHORHOMBIC SYSTEM
    1. Normal Group (25). Barite Type
    2. Hemimorphic Group (26). Calamine Type
    3. Sphenoidal Group (27). Epsomite Type
    Mathematical Relations of the Orthorhombic System

PAGE
V. MONOCLINIC SYSTEM 98
  1. Normal Group (28). Gypsum Type 99
  2. Hemimorphic Group (29) 103
  3. Clinohedral Group (30). Clinohedrite Type 104
  Mathematical Relations of the Monoclinic System 104
VI. TRICLINIC SYSTEM 106
  1. Normal Group (31). Axinite Type 107
  2. Asymmetric Group (32) 109
  Mathematical Relations of the Triclinic System 109
MEASUREMENT OF THE ANGLES OF CRYSTALS 112
COMPOUND OR TWIN CRYSTALS 118
  Examples of Important Methods of Twinning 123
  Regular Grouping of Crystals 131
IRREGULARITIES OF CRYSTALS 132
  1. Variations in the Forms and Dimensions of Crystals 133
  2. Imperfections of the Surfaces of Crystals 136
  3. Variations in the Angles of Crystals 138
  4. Internal Imperfection and Inclusions 138
CRYSTALLINE AGGREGATES 142

PART II. PHYSICAL MINERALOGY.

PHYSICAL CHARACTERS OF MINERALS 145
I. Characters depending upon Cohesion and Elasticity 146
II. Specific Gravity, or Relative Density 156
III. Characters depending upon Light 160
  General Principles of Optics 160
  Optical Instruments and Methods 180
  General Optical Characters of Minerals 186
    1. Diaphaneity 186
    2. Color 186
    3. Luster 188
  Special Optical Characters of Minerals belonging to the different Systems 192
    A. Isometric Crystals 193
    B. Uniaxial Crystals 193
      General Optical Relations 193
      Optical Examination of Uniaxial Crystals 197
    C. Biaxial Crystals 203
      General Optical Relations 203
      Optical Examination of Biaxial Crystals 210
IV. Characters depending upon Heat 231
V. Characters depending upon Electricity and Magnetism 234
VI. Taste and Odor 238

PART III. CHEMICAL MINERALOGY.

GENERAL PRINCIPLES OF CHEMISTRY AS APPLIED TO MINERALS 239
CHEMICAL EXAMINATION OF MINERALS 254
  Examination in the Wet Way 254
  Examination by Means of the Blowpipe 256

PART IV. DESCRIPTIVE MINERALOGY.

PAGE
NATIVE ELEMENTS........ 271
SULPHIDES, SELENIDES, TELLURIDES, ETC........ 282
SULPHO-SALTS........ 306
CHLORIDES, BROMIDES, IODIDES, FLUORIDES........ 317
OXIDES........ 324
CARBONATES........ 353
SILICATES........ 368
TITANO-SILICATES, TITANATES........ 485
NIOBATES, TANTALATES........ 489
PHOSPHATES, ARSENATES, VANADATES, ETC........ 494
NITRATES........ 517
BORATES........ 518
URANATES........ 521
SULPHATES, CHROMATES, ETC........ 523
TUNGSTATES, MOLYBDATES........ 539
OXALATES, MELLATES........ 542
HYDROCARBON COMPOUNDS........ 543

APPENDIX A.

DRAWINGS OF CRYSTAL FIGURES, AND OF PROJECTIONS........ 547

APPENDIX B.

TABLES TO BE USED IN THE DETERMINATION OF MINERALS........ 557

GENERAL INDEX........ 570
INDEX TO SPECIES........ 579

INTRODUCTION.

---

1. THE SCIENCE OF MINERALOGY treats of those inorganic species called *minerals*, which together in rock masses or in isolated form make up the material of the crust of the earth, and of other bodies in the universe so far as it is possible to study them in the form of meteorites.

2. **Definition of a Mineral.**—*A Mineral is a body produced by the processes of inorganic nature, having a definite chemical composition and, if formed under favorable conditions, a certain characteristic molecular structure which is exhibited in its crystalline form and other physical properties.*

This definition calls for some further explanation.

First of all, a mineral must be a *homogeneous* substance, even when minutely examined by the microscope; further, it must have a *definite chemical composition*, capable of being expressed by a chemical formula. Thus, much basalt appears to be homogeneous to the eye, but when examined under the microscope in thin sections it is seen to be made up of different substances, each having characters of its own. Again, obsidian, or volcanic glass, though it may be essentially homogeneous, has not a definite composition corresponding to a specific chemical formula, and is hence classed as a rock, not as a mineral species. Further, several substances, as tachylyte, hyalomelane, etc., which at one time passed as minerals, have been relegated to petrology, because it has been shown that they are only local forms of basalt, retaining an apparently homogeneous form due to rapid cooling.

Again, a mineral has in all cases a *definite molecular structure*, unless the conditions of formation have been such as to prevent this, which is rarely true. This molecular structure, as will be shown later, manifests itself in the physical characters and especially in the external crystalline form.

It is customary, as a matter of convenience, to limit the name mineral to those compounds which have been formed by the processes of nature alone, while compounds made in the laboratory or the smelting-furnace are at most called artificial minerals. Further, mineral substances which have been produced through the agency of organic life are not included among minerals, as the pearl of an oyster, the opal-silica (tabasheer) secreted by the bamboo, etc. Finally, mineral species are, as a rule, limited to *solid substances;* the only liquids included being metallic mercury and water. Petroleum, or mineral oil, is not properly a homogeneous substance, consisting rather of several hydrocarbon compounds; it is hence not a mineral species.

It is obvious from the above that minerals, in the somewhat restricted sense usually adopted, constitute only a part of what is often called the Mineral Kingdom.

3. Scope of Mineralogy.—In the following pages, the general subject of Mineralogy is treated under the following heads:

(1) *Crystallography.*—This comprises a discussion of crystals in general and especially of the crystalline forms of mineral species.

(2) *Physical Mineralogy.*—This includes a discussion of the physical characters of minerals, that is, those depending upon cohesion and elasticity, density, light, heat, electricity, and so on.

(3) *Chemical Mineralogy.*—Under this head are presented briefly the general principles of chemistry as applied to mineral species; their characters as chemical compounds are described, also the methods of investigating them from the chemical side by the blowpipe and other means.

(4) *Descriptive Mineralogy.*—This includes the classification of minerals and the description of each species with its varieties, especially in its relations to closely allied species, as regards crystalline form, physical and chemical characters, occurrence in nature, and other points.

4. Literature.—Reference is made to the Introduction to the Sixth Edition of Dana's System of Mineralogy, pp. xlv–lxi, for an extended list of independent works on Mineralogy up to 1892; the names are also given of the many scientific periodicals which contain original memoirs on mineralogical subjects. For the convenience of the student the titles of a few works, mostly of a general character, are given here. Further references to the literature of Mineralogy are introduced through the first half of this work, particularly at the end of the sections dealing with special subjects.

Crystallography and Physical Mineralogy.

EARLY WORKS* include those of Romé de l'Isle, 1772; Haüy, 1822; Neumann, Krystallonomie, 1823, and Krystallographie, 1825: Kupffer, 1825; Grassmann, Krystallonomie, 1829; Naumann, 1829 and later; Quenstedt, 1846 (also 1873); Miller, 1839 and 1863; Grailich, 1856; Kopp, 1862; von Lang, 1866; Bravais, Études Crist., Paris, 1866 (1849); Schrauf, 1866–68; Rose-Sadebeck, 1873.

RECENT WORKS include the following:

Bauerman. Text Book of Systematic Mineralogy, 1881.

Goldschmidt. Index der Krystallformen der Mineralien; 3 vols., 1886–91. Also Anwendung der Linearprojection zum Berechnen der Krystalle, 1887.

Groth. Physikalische Krystallographie und Einleitung in die krystallographische Kenntniss der wichtigeren Substanzen, 1876. 3d ed., 1894–95.

Klein. Einleitung in die Krystallberechnung, 1876.

Liebisch. Geometrische Krystallographie, 1881. Physikalische Krystallographie, 1891.

Mallard. Traité de Cristallographie géométrique et physique; vol. 1, 1879; vol. 2, 1884.

Sadebeck. Angewandte Krystallographie (Rose's Krystallographie, II. Band), 1876.

Sohncke. Entwickelung einer Theorie der Krystallstruktur, 1879.

Story-Maskelyne. Crystallography: the Morphology of Crystals, 1895.

Websky. Anwendung der Linearprojection zum Berechnen der Krystalle (Rose's Krystallographie. III. Band). 1887.

Williams. Elements of Crystallography, 1890.

Wülfing. Tabellarische Uebersicht der einfachen Formen der 32 krystallographischen Symmetriegruppen, etc., 1895.

In PHYSICAL MINERALOGY the most important general works are those of Schrauf (1868), Groth (1876–1895), Mallard (1884), Liebisch (1891), mentioned in the above list; also Rosenbusch, Mikr. Physiographie, etc. (1892). In addition to these (to which might be added the names of some general works on Physics) memoirs of especial importance on the different subjects are enumerated in many cases at the end of the respective sections of this work.

---

* The full titles of many of these are given in pp. li–lxi of Dana's System of Mineralogy, 1892.

General Mineralogy.

Of the many works, a knowledge of which is needed by one who wishes a full acquaintance with the historical development of Mineralogy, the following are particularly important. Very early works include those of Theophrastus, Pliny, Linnæus, Wallerius, Cronstedt, Werner, Bergmann, Klaproth.

Within the nineteenth century: Haüy's Treatise, 1801, 1822; Jameson, 1816, 1820; Werner's Letztes Mineral-System, 1817; Cleaveland's Mineralogy, 1816, 1822; Leonhard's Handbuch, 1821, 1826; Mohs's Min., 1822; Haidinger's translation of Mohs, 1824; Breithaupt's Charakteristik, 1820, 1823, 1832; Beudant's Treatise, 1824, 1832; Phillips's Min., 1823, 1837; Shepard's Min., 1832–35, and later editions; von Kobell's Grundzüge, 1838; Mohs's Min., 1839; Breithaupt's Min., 1836–1847; Haidinger's Handbuch, 1845; Naumann's Min., 1846 and later; Hausmann's Handbuch, 1847; Dufrénoy's Min., 1844–1847 (also 1856–1859); Brooke & Miller, 1852; J. D. Dana's System of 1837, 1844, 1850, 1854, 1868.

More Recent Works are the following:

Bauer. Lehrbuch der Mineralogie, 1886.

Bauerman. Text-Book of Descriptive Mineralogy, 1884.

Baumhauer. Das Reich der Krystalle, 1889.

Blum. Lehrbuch der Mineralogie. 4th ed., 1873–1874.

Dana, E. S. Dana's System of Mineralogy, 6th ed., New York, 1892. Also (elementary) Minerals and How to study them, New York, 1895.

Dana, J. D. Manual of Mineralogy and Petrography, 4th ed., New York, 1887.

Des Cloizeaux. Manuel de Minéralogie; vol. 1, 1862; vol. 2, 1er Fasc., 1874; 2me. 1893.

Groth. Tabellarische Uebersicht der Mineralien, 1874; 3d ed., 1889; 4th ed., 1898. Die Mineralien-Sammlung der Universität Strassburg. 1878.

Hintze. Handbuch der Mineralogie, vol. 2 (Silicates and Titanates), Leipzig, 1889–1897.

Lacroix. Minéralogie de la France et de ses Colonies, 2 vols., 1893–96.

Luedecke. Die Minerale des Harzes, 1896.

Koksharov. Materialen zur Mineralogie Russlands, St. Petersburg; vol. 1, 1853–54; vol. 10, 1888–91.

Kunz. Gems and Precious Stones of North America, 1890.

Schrauf. Atlas der Krystall-Formen des Mineralreiches, 4to, vol. 1, A–C, 1865–1877.

Tschermak. Lehrbuch der Mineralogie, 1884; 5th ed., 1897.

Weisbach. Synopsis Mineralogica, systematische Uebersicht des Mineralreiches, 1875.

Zirkel. 13th edition of Naumann's Mineralogy, Leipzig, 1897.

Wülfing. Die Meteoriten in Sammlungen, etc., 1897 (earlier works on related subjects, see Dana's System, p. 32).

For a catalogue of localities of minerals in the United States and Canada see the volume (51 pp.) reprinted from Dana's System, 6th ed. See also the volumes on the Mineral Resources of the United States published (since 1882) under the auspices of the U. S. Geological Survey.

Chemical and Determinative Mineralogy.

Bischoff. Lehrbuch der chemischen und physikalischen Geologie, 1847–54; 2d ed., 1863–66. (Also an English edition.)

Blum. Die Pseudomorphosen des Mineralreichs, 1843. With 4 Nachträge, 1847–1879.

Brush. Manual of Determinative Mineralogy, with an Introduction on Blowpipe Analysis; New York, 1875; 3d ed., 1878. Also new edition by **Penfield**, 1896.

Doelter. Allgemeine chemische Mineralogie. Leipzig, 1890.

Endlich. Manual of Qualitative Blowpipe Analysis, New York, 1892.

Kobell, F. von. Tafeln zur Bestimmung der Mineralien mittelst einfacher chemischer Versuche auf trockenem und nassem Wege, 11te Auflage, 1878.

Rammelsberg. Handbuch der krystallographisch-physikalischen Chemie, Leipzig, 1881–82. Handbuch der Mineralchemie, 2d ed., 1875. Ergänzungsheft, 1, 1886; 2, 1895.

Roth. Allgemeine und chemische Geologie; vol. 1, Bildung u. Umbildung der Mineralien, etc., 1879; 2, Petrographie, 1887–1890.

Volger. Studien zur Entwicklungsgeschichte der Mineralien, 1854.

Websky. Die Mineral Species nach den für das specifische Gewicht derselben angenommenen und gefundenen Werthen, Breslau, 1868.

Weisbach. Tabellen zur Bestimmung der Mineralien nach äusseren Kennzeichen.

8te Auflage, 1886. Also founded on Weisbach's work, **Frazer's** Tables for the determination of minerals, 4th ed.. 1897.

Microscopic Examination of Minerals.[*]

Cohen, E. Sammlung von Mikrophotographieen zur Veranschaulichung der mikroskopischen Structur von Mineralien und Gesteinen, 1881–82.

Doelter. Die Bestimmung der petrographisch wichtigeren Mineralien durch das Mikroskop, 1876.

Fischer. Kritische mikroskopisch-mineralogische Studien, Freiburg, 1869–1873.

Fouqué-Lévy. Minéralogie micrographique, roches éruptives Françaises, 1879.

Lévy-Lacroix. Les minéraux des roches, 1888.

Rosenbusch. Mikroskopische Physiographie der petrographisch-wichtigen Mineralien, 1873; 3d ed., 1892. Accompanied by Hülfstabellen zur mikroskopischen Mineralbestimmung, 1888. Also English translation and abridgment of the above work by Iddings, 1888. Mikroskopische Physiographie der massigen Gesteine, 1877; 3d ed., 1896.

Thoulet. Contributions à l'étude des propriétés physiques et chimiques des minéraux microscopiques.

Tschermak. Die mikroskopische Beschaffenheit der Meteoriten, 1883.

Zirkel. Die mikroskopische Beschaffenheit der Mineralien und Gesteine, 1873. Also Petrographie, 3 vols., 1893–94.

Artificial Formation of Minerals.

Gurlt. Uebersicht der pyrogeneten künstlichen Mineralien, namentlich der krystallisirten Hüttenerzeugnisse, 1857.

Fuchs. Die künstlich dargestellten Mineralien, 1872.

Daubrée. Études synthetique de Géologie expérimentale, Paris, 1879.

Fouqué and **M. Lévy.** Synthèse des Minéraux et des Roches, 1882.

Bourgeois. Réproduction artificielle des Minéraux, 1884.

Meunier. Les méthodes de synthèse en Minéralogie.

Mineralogical Journals.

The following Journals are largely devoted to original papers on Mineralogy:

Bull. Soc. Min. Bulletin de la Société Française de Minéralogie, vol. 1, 1878; **20**, 1897.

Jb. Min. Neues Jahrbuch für Mineralogie, Geologie und Palæontologie, etc., from 1833.

Min. Mag. The Mineralogical Magazine and Journal of the Mineralogical Society of Gt. Britain, vol. 1, 1876; **11**, 1896–97.

Min. petr. Mitth. Mineralogische und petrographische Mittheilungen, vol. 1, 1878; **17**, 1897. Earlier, from 1871, Mineralogische Mittheilungen gesammelt von G. Tschermak.

Zs. Kryst. Zeitschrift für Krystallographie und Mineralogie. Edited by P. Groth. vol. 1, 1877; **28**, 1897.

ABBREVIATIONS.

Ax. pl.	Plane of the optic axes.	**H.**	Hardness.
Bx, Bx$_a$.	Acute bisectrix (p. 208).	**Obs.**	Observations on occurrence, etc.
Bx$_o$.	Obtuse bisectrix (p. 208).	**O.F.**	Oxidizing Flame (p. 257).
B.B.	Before the Blowpipe (p. 256).	**Pyr.**	Pyrognostics or blowpipe and allied characters.
Comp.	Composition.		
Diff.	Differences, or distinctive characters.	**O. Ratio.**	Oxygen Ratio (p. 249).
		R.F.	Reducing Flame (p. 257).
G.	Specific Gravity.	**Var.**	Varieties.

The sign $\wedge$ is used to indicate the angle between two faces of a crystal, as *am* (100 $\wedge$ 110) = 44° 30′.

---

[*] See the bibliography given by Rosenbusch.

PART I. CRYSTALLOGRAPHY.

GENERAL MORPHOLOGICAL RELATIONS OF CRYSTALS.

5. Crystallography.—The subject of Crystallography includes the description of the characters of crystals in general; of the various forms of crystals and their division into groups and systems; of the methods of studying crystals, including the determination of the mathematical relations of their faces, and the measurement of the angles between them; finally, a description of compound or twin crystals, of irregularities in crystals, of crystalline aggregates, and of pseudomorphous crystals.

Allied to Crystallography is the subject of *Crystallogeny*, which describes the methods of making crystals which may be applied in the laboratory, and discusses the theories of their origin in nature. This department is only briefly touched upon in the present work.

6. Definition of a Crystal.—*A crystal*[*] *is the regular polyhedral form, bounded by smooth surfaces, which is assumed by a chemical compound, under the action of its intermolecular forces, when passing, under suitable conditions, from the state of a liquid or gas to that of a solid.*

As expressed in the foregoing definition, a crystal is characterized, first, by its definite internal molecular structure, and, second, by its external form. A crystal is the *normal* form of a mineral species, as of all solid chemical compounds; but the conditions suitable for the formation of a crystal of ideal perfection in symmetry of form and smoothness of surface are never realized. Further, many species usually occur not in distinct crystals, but in massive form, and in some exceptional cases the definite molecular structure is absent.

7. Molecular Structure in General.—By definite molecular structure is meant the special arrangement which the physical units, called *molecules*,[†] assume under the action of the forces exerted between them during the formation of the solid. Some remarks are given in a later article (p. 18 *et seq.*) in regard to the kinds of molecular arrangement theoretically possible, and their relation to the symmetry of the different groups and systems of crystals.

---

[*] In its original signification the term *crystal* was applied only to crystals of quartz, which the ancient philosophers believed to be *water* congealed by intense cold. Hence the term, from κρύσταλλος, *ice*.

[†] The relation between *atoms*, *chemical molecules*, and *physical molecules* is explained under the chapter on Chemical Mineralogy. The molecules here spoken of are the physical molecules.

The definite molecular structure is the essential character of a crystal, and the external form is only one of the ways, although the most important, in which this structure is manifested. Thus it is found that all similar directions in a crystal, or a fragment of a crystal, have like physical characters,* as of elasticity, cohesion, action on light, etc. This is clearly shown by the cleavage, or natural tendency to fracture in certain directions, yielding more or less smooth surfaces; as the cubic cleavage of galena, or the rhombohedral cleavage of calcite. It is evident, therefore, that a small crystal differs from a large one only in size, and that a fragment of a crystal is itself essentially a crystal in all its physical relations, though showing no crystalline faces.

Further, the external form without the corresponding molecular structure does not make a solid a crystal. A model of glass or wood, on the one hand, is not a crystal, though having its external form, because there is no relation between form and structure. Also, an octahedron of malachite, having the form of the crystal of cuprite from which it has been derived by chemical alteration, is not a crystal of malachite.

On the other hand, if the natural external faces are wanting, the solid is not called a crystal. A cleavage octahedron of fluorite and a cleavage rhombohedron of calcite are not properly crystals, because the surfaces have been yielded by fracture and not by the natural molecular growth of the crystal.

8. Crystalline and Amorphous.—When a mineral shows no external crystalline form, it is said to be *massive*. It may, however, have a definite molecular structure, and then it is said to be *crystalline*. If this structure, as shown by the cleavage, or by optical means, is the same in all parallel directions through the mass, it is described as a single individual. If it varies from grain to grain, or fiber to fiber, it is said to be a *crystalline aggregate*,† since it is in fact made up of a multitude of individuals.

Thus in a granular mass of galena or calcite, it may be possible to separate the fragments from one another, each with its characteristic cubic, or rhombohedral, cleavage. Even if the individuals are so small that they cannot be separated, yet the cleavage, and hence the crystalline structure, may be evident from the spangling of a freshly broken surface, as with fine-grained statuary marble. Or, again, this aggregate structure may be so fine that the crystalline structure can only be resolved by optical methods with the aid of the microscope. In all these cases, the structure is said to be *crystalline*.

If optical means show a more or less distinct crystalline structure, which, however, cannot be resolved into individuals, the mass is said to be *crypto-crystalline*; this is true of some massive varieties of quartz.

If the definite molecular structure is entirely wanting, and all directions in the mass are sensibly the same, the substance is said to be *amorphous*. This is true of a piece of glass, and nearly so of opal. The amorphous state is rare among minerals.

A piece of feldspar which has been fused and cooled suddenly may be in the glass-like amorphous condition as regards absence of definite molecular structure. But even in such cases there is a tendency to go over into the crystalline condition by molecular rearrangement. A transparent amorphous mass of arsenic trioxide (As_2O_3), formed by fusion, becomes opaque and crystalline after a time. Similarly the steel beams of a railroad bridge may gradually become crystalline and thus lose some of their original strength because of the molecular rearrangement made possible by the vibrations caused by the frequent jar of passing trains. The microscopic study of rocks reveals many cases in which an analogous change in molecular structure has taken place in a solid mass, as caused, for example, by great pressure.

---

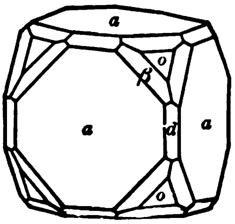
* This subject is further elucidated in the chapter devoted to Physical Mineralogy, where it is also shown that, with respect to many, but not all, of the physical characters, the converse of this proposition is true, viz., that unlike directions in a crystal have in general unlike properties.

† The consideration of the various forms of crystalline aggregates is postponed to the end of the present chapter.

9. External Form.—A crystal is bounded by smooth plane surfaces, called faces or planes,* showing in their arrangement a certain characteristic symmetry, and related to each other by definite mathematical laws.

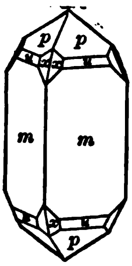
Thus, without inquiring, at the moment, into the exact meaning of the term symmetry as applied to crystals, and the kinds of symmetry possible, which will be explained in detail later, it is apparent that the accompanying figures, 1–3, show the external form spoken of. They represent, therefore, certain definite types.

1.



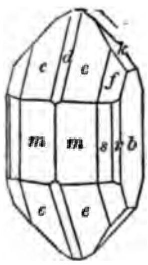
Galena.

2.



Zircon.

3.



Chrysolite.

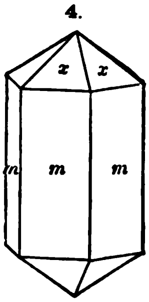
10. Variation of Form and Surface.—Actual crystals deviate, within certain limits, from the ideal forms.

First, there may be variation in the size of like faces, thus producing what are defined later as *distorted forms.* In the second place, the faces are rarely absolutely smooth and brilliant; commonly they lack perfect polish, and they may even be rough or more or less covered with fine parallel lines (called striations), or show minute elevations, depressions or other peculiarities. Both the above subjects are discussed in detail in another place.

It may be noted in passing that the characters of natural faces, just alluded to, in general make it easy to distinguish between them and a face artificially ground, on the one hand, like the facet of a cut gem; or, on the other hand, the splintery uneven surface yielded by cleavage.

11. Constancy of Angle in the Same Species.—The crystals of any species are essentially constant in the angle of inclination between like faces, wherever they are found, and whether products of nature or of the laboratory. These angles, therefore, form one of the distinguishing characters of a species.

4.



Apatite.

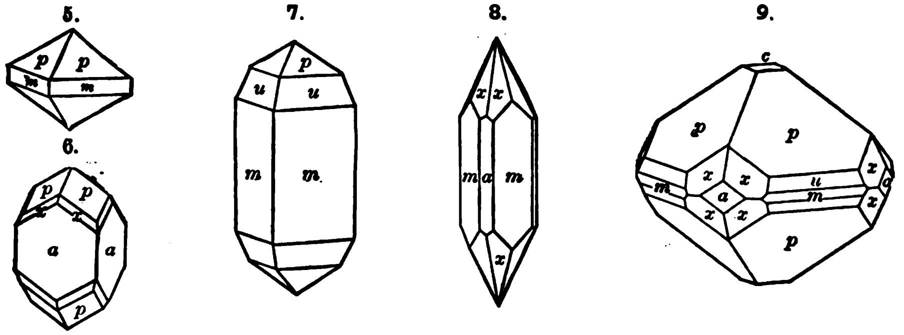
Thus, in Fig. 4, of apatite, the angle between the adjacent faces *x* and

---

* This latter word is usually limited to cases where the direction, rather than the definite surface itself, is designated.

m (130° 18′) is the same for any two like faces, similarly situated with reference to each other. Further, this angle is constant for the species, differing but little on crystals from different localities. Moreover, the angles between all the faces on crystals of the same species (cf. Figs. 5–9 of zircon below) are more or less closely connected together by certain definite mathematical laws.

12. Diversity of Form, or Habit.—While in the crystals of a given species there is constancy of angle between like faces, the forms of the crystals may be exceedingly diverse. The accompanying figures (5–9) are examples of a few of the forms of the species zircon. There is hardly any limit to the number of faces which may occur, and as their relative size changes, the *habit*, as it is called, may vary indefinitely. Yet for the crystals of each species, the angles between like faces are essentially constant.



Crystals of Zircon.

13. Diversity of Size.—Crystals occur of all sizes, from the merest microscopic point to a yard or more in diameter. It is important to understand, however, that in a minute crystal the development is as complete as with a large one. Indeed the highest perfection of form and transparency is found only in crystals of small size.

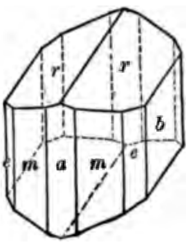
A single crystal of quartz, now at Milan, is three and a quarter feet long and five and a half in circumference, and its weight is estimated at eight hundred and seventy pounds. A single cavity in a vein of quartz near the Tiefen Glacier, in Switzerland, discovered in 1867, afforded smoky quartz crystals weighing in the aggregate about 20,000 pounds; a considerable number of the single crys'als having a weight of 200 to 250 pounds, or even more. A gigantic beryl from Acworth, New Hampshire, measured four feet in length and two and a half in circumference; another, from Grafton, was over four feet long, and thirty-two inches in one of its diameters, and weighed about two and a half tons.

14. Symmetry in General.—The faces of a crystal are arranged according to certain laws of symmetry, and this symmetry is the natural basis of the division of crystals into groups and systems. The symmetry may be defined relatively to (1) *a plane of symmetry*, (2) *an axis of symmetry*, and (3) *a center of symmetry*.

These different kinds of symmetry may, or may not, be combined in the same crystal. It will be shown later that there is one group the crystals of which have neither center, axis, nor plane of symmetry; another where there is only a center of symmetry. On the other hand, some groups have all these elements of symmetry represented.

15. Planes of Symmetry.—A solid is said to be geometrically * symmetrical with reference to a plane of symmetry when for each face, edge, or solid angle there is another similar face, edge, or angle which has a like position with reference to this plane. Thus it is obvious that the crystal of amphibole, shown in Fig. 10, is symmetrical with reference to a central plane of symmetry, parallel to the face *b*, passing vertically through the edge formed by the faces *r*, *r* and through the middle of the face *a*.

10.

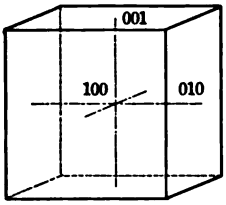


Amphibole.

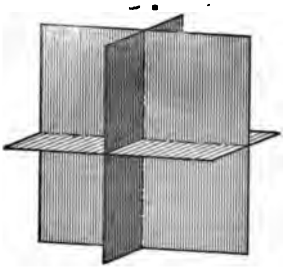
In the ideal crystal this symmetry is *right symmetry* in the geometrical sense, where every point on the one side of the plane of symmetry has a corresponding point at equal distances on the other side, measured on a line normal to it. In other words, in the ideal geometrical symmetry, one half of the crystal is the exact *mirror-image* of the other half.

A crystal may have as many as nine planes of symmetry, three of one set and six of another, as is illustrated by the cube † (Fig. 11). Here the planes of the first set pass through the crystal parallel to the cubic faces; they are shown in Fig. 12. The planes of the second set join the opposite cubic edges. On the other hand, some crystals have no plane of symmetry.

11.



12.



16. Axes of Symmetry.—If a solid can be revolved through a certain number of degrees about some line as an axis, with the result that it again occupies precisely the same position in space as at first, it is said to have an axis of symmetry. There are four different kinds of axes of symmetry among crystals; they are defined according to the angular revolution needed in each case, that is, by the number of times which the crystal repeats itself in a complete revolution of 360°.

(*a*) A crystal is said to have an axis of *binary*, or twofold, symmetry when a revolution of 180° produces the result named above; in other words, when it repeats itself twice in a complete revolution. This is true of the crystal shown in Fig. 13 with respect to the vertical axis (and indeed each of the horizontal axes also).

(*b*) A crystal has an axis of *trigonal*, or threefold, symmetry when a revolution of 120° is needed ; that is, when it repeats itself three times in a complete revolution. The vertical axis of the crystal shown in Fig. 14 is an axis of trigonal symmetry.

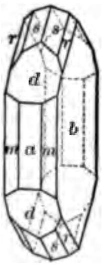
---

* The relation between the ideal geometrical symmetry and the actual crystallographic symmetry is discussed in Art. 18.

† This is the cube of the normal group of the isometric system.

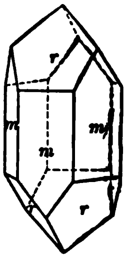
(*c*) A crystal has an axis of *tetragonal*, or fourfold, symmetry when a revolution of 90° is called for; in other words, when it repeats itself four times in a complete revolution. The vertical axis in the crystal shown in Fig. 15 is such an axis.

13.



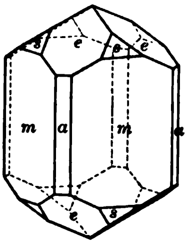
Polycrase.

14.



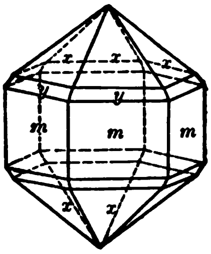
Tellurium.

15.



Rutile.

16.

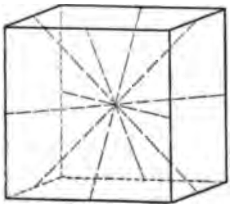


Mimetite.

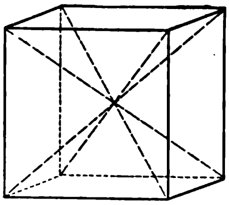
(*d*) Finally, a crystal has an axis of ***hexagonal***, or sixfold, symmetry when a revolution of 60° is called for; in other words, when it repeats itself six times in a complete revolution. This is illustrated by Fig. 16.

The cube* illustrates three of the four possible kinds of symmetry with respect to axes of symmetry. It has six axes of binary symmetry joining the middle points of opposite edges (Fig. 17). It has four axes of trigonal symmetry, joining the opposite solid angles (Fig. 18). It has, finally, three axes of tetragonal symmetry joining the middle points of opposite faces (Fig. 19).

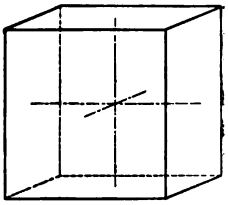
17.



18.



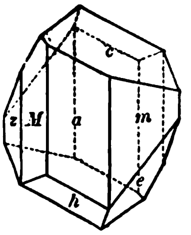
19.



17. Center of Symmetry.—Most crystals, besides planes and axes of symmetry, have also a center of symmetry. On the other hand, a crystal, though possessing neither plane nor axis of symmetry, may yet be symmetrical with reference to a point, its center. This last is true of the triclinic crystal shown in Fig. 20, in which it follows that every face, edge, and solid angle has a face, edge, and angle similar to it in the opposite half of the crystal.

There is another method of viewing the symmetry in this last case, which is adopted by some authors. If the crystal be thought of as divided into two similar halves by a plane parallel to any one of its faces, and one half be revolved 180° about an axis normal to this face, this half would be brought into a position in which it would be the mirror-image of the remaining half. This symmetry is hence described as *compound symmetry* with reference to an axis of binary symmetry and a plane normal to it, both taken together. This method is not followed here since, though having certain theoretical advantages, it is likely to confuse the student meeting the problems of crystallography for the first time.

20.



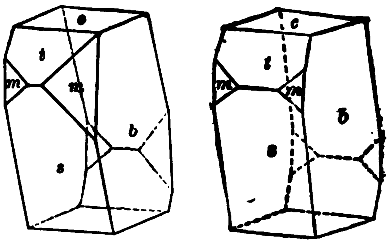
Amblygonite.

---

* This is again the cube of the normal group of the isometric system.

18. Relation of Geometrical to Crystallographic Symmetry.—Since the symmetry in the arrangement of the faces of a crystal is an expression of the internal molecular structure, which in general is alike in all parallel directions, the *relative size* of the faces and their *distance* from the plane or axis of symmetry are of no moment, their *angular position* alone is essential. Hence Fig. 21 has as truly a vertical plane of symmetry (parallel to *b*) as Fig. 22 if the faces have exactly the same angular position as in that, although the strict geometrical definition* could not be applied to it.

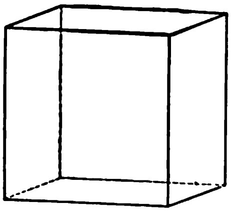
21. 22.



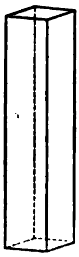
Heulandite.

Also in a normal cube (Fig. 23) the three central planes parallel to each pair of cubic faces are like planes of symmetry, as stated in Art. 15. But a crystal is still crystallographically a cube, though deviating widely from the requirements of the strict geometrical definition, as shown in Figs. 24, 25, if only it can be proved, *e.g.* by cleavage, the physical nature of the faces, or by optical means, that the three pairs of faces are like faces, independently of their size, or, in other words, that the molecular structure is the same in the three directions normal to them.

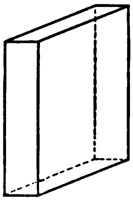
23.



24.

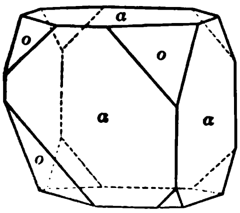


25.

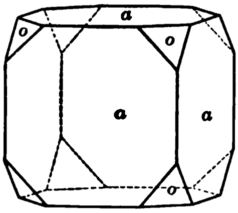


Further, in the case of a normal cube, a face of an octahedron on any solid angle requires, as explained beyond, similar faces on the other angles. It is *not* necessary, however, that these eight faces should be of equal size, for in the crystallographic sense Fig. 26 is as truly symmetrical with reference to the planes named as Fig. 27.

26.



27.



19. On the other hand, the molecular and hence the crystallographic symmetry is not always that which the geometrical form would suggest. Thus, deferring for the moment the consideration of pseudo-symmetry, an illustration of the fact stated is afforded by the cube.

---

* It is to be noted that the perspective figures of crystals always show the geometrically ideal form, in which like faces, edges, and angles have the same shape, size, and position. In other words, the ideal crystal is uniformly represented as having the symmetry called for by the strict geometrical definition.

It has already been implied and will be fully explained later that while the cube of the normal group of the isometric system has the symmetry described in Arts. 15, 16, a cube of the same geometrical form but belonging molecularly, for example, to the tetrahedral group, has no planes of symmetry parallel to the faces, only the six diagonal planes ; further, though the four axes shown in Fig. 18 are still axes of trigonal symmetry, the cubic axes (Fig. 19) are axes of binary symmetry only, and there are no axes of symmetry corresponding to those represented in Fig. 17. Other more complex cases will be described later.

Further, a crystal having interfacial angles of 90° is not necessarily a cube; in other words, the angular relations of the faces do not show in this case whether the figure is bounded by six like faces; or whether only two are alike and the third unlike; or, finally, whether there are three pairs of unlike faces. The question must be decided, in such cases, by the molecular structure as indicated by the physical nature of the surfaces, by the cleavage, or by other physical characters, as pyro-electricity, those connected with light phenomena, etc.

Still again, the student will learn later that the decision reached in regard to the symmetry to which a crystal belongs, based upon the *distribution* of the faces, is only preliminary and approximate, and before being finally accepted it must be confirmed, first, by accurate measurements, and, second, by a minute study of the physical characters as just insisted upon.

The method based upon the physical characters, which gives most conclusive results and admits of the widest application, is the skillful etching of the surface of the crystal by some appropriate solvent. By this means there are, in general, produced upon it minute depressions the shape of which always conforms to the symmetry in the arrangement of the molecules. This process, which is in part essentially one involving the dissection of the molecular structure, is more particularly discussed in the chapter on Physical Mineralogy.

20. Pseudo-symmetry.—The crystals of certain species approximate closely in angle, and therefore in apparent symmetry, to the requirements of a system higher in symmetry than that to which they actually belong: they are then said to exhibit *pseudo-symmetry.* Numerous examples are given under the different systems. Thus the micas have been shown to be truly monoclinic in crystallization, though in angle they seem to be in some cases rhombohedral, in others orthorhombic.

It will be shown later that compound, or twin, crystals may also simulate by their regular grouping a higher grade of symmetry than that which belongs to the single crystal. Such crystals also exhibit pseudo-symmetry and are specifically called *mimetic.* Thus aragonite is an example of an orthorhombic species, whose crystals often imitate by twinning those of the hexagonal system.* Again, a highly complex twinned crystal of the monoclinic species, phillipsite, may have nearly the form of a rhombic dodecahedron of the isometric system. This kind of pseudo-symmetry also occurs among the groups of a single system, since a crystal belonging to a group of low symmetry may by twinning gain the geometrical symmetry of the corresponding form of the normal group. This is illustrated by a twinned crystal of scheelite like that figured (Fig. 378) in the chapter on twin crystals.

Pseudo-symmetry of still another kind, where there is an imitation of the symmetry of another system of lower grade, is particularly common in crystals of the isometric system (*e.g.*, gold, copper). The result is reached in such cases by an abnormal development or "distortion" in the direction of certain axes of symmetry. This subject is discussed and illustrated on a later page.

---

* The terms *pseudo-hexagonal*, etc., used in this and similar cases explain themselves.

21. Possible Groups of Symmetry.—The theoretical consideration of the different kinds of symmetry possible among crystals built up of like molecules, as explained in Arts. **30–32**, has led to the conclusion that there are thirty-two (32) types in all, differing with respect to the combination of the different symmetry elements just described. Of these thirty-two natural groups among crystals based upon their symmetry, seven groups include by far the larger number of crystallized minerals. Besides these, some thirteen or fourteen others are distinctly represented, though several of these are of rare occurrence. Further, eight or nine others, making in all twenty-nine or thirty, are known among crystallized salts made in the laboratory. The characters of each of the thirty-two groups are given under the discussion of the several crystalline systems.

22. Crystallographic Axes.—In the description of the form of a crystal, especially as regards the position of its faces, it is found convenient to assume, after the methods of analytical geometry, definite lengths of certain lines passing through the center of the ideal crystal, as a basis of reference. (See further Art. **33** *et seq.*)

These lines are called the *crystallographic axes.* Their direction is to a greater or less extent fixed by the symmetry of the crystals, for an axis of symmetry is in almost all cases* a possible crystallographic axis. Further, their unit lengths are fixed sometimes by the symmetry, sometimes by the faces assumed as fundamental, *i.e.*, the unit forms in the sense defined later. The dotted lines shown in Fig. 19 are the crystallographic axes to which the cubic faces are referred.

23. Systems of Crystallization.—The thirty-two possible crystalline groups, distinguished from one another by their symmetry, are classified in this work under six systems, each characterized by the relative lengths and inclinations of the assumed crystallographic axes. These are as follows:

I. ISOMETRIC SYSTEM. Three equal axes at right angles to each other.

II. TETRAGONAL SYSTEM. Three axes at right angles to each other, two of them—the lateral axes—equal, the third—the vertical axis—longer or shorter.

III. HEXAGONAL SXSTEM. Four axes, three equal lateral axes in one plane intersecting at angles of 60°, and a vertical axis at right angles to this plane and longer or shorter.

IV. ORTHORHOMBIC SYSTEM. Three axes at right angles to each other, but all of different lengths.

V. MONOCLINIC SYSTEM. Three axes unequal in length, and having one of their intersections oblique, the two other intersections equal to 90°.

VI. TRICLINIC SYSTEM. Three unequal axes with mutually oblique intersections.

The systems of crystallization have been variously named by different authors, as follows:

ISOMETRIC. *Tessular* of Mohs and Haidinger; *Isometric* of Hausmann; *Tesseral* of Naumann; *Regular* of Weiss and Rose; *Cubic* of Dufrénoy, Miller, Des Cloizeaux; *Monometric* of the earlier editions of Dana's System of Mineralogy.

---

* Exceptions are found in the isometric system, where the axes must necessarily be the axes of tetragonal symmetry (Fig. 19), and cannot be those of binary or trigonal symmetry (Figs. 17, 18).

TETRAGONAL. *Pyramidal* of Mohs; Viergliedrige, or *Zwei-und-einaxige*, of Weiss; *Tetragonal* of Naumann; *Monodimetric* of Hausmann; *Quadratic* of von Kobell; *Dimetric* of early editions of Dana's System.

HEXAGONAL. *Rhombohedral* of Mohs; Sechsgliedrige, or *Drei-und-einaxige* of Weiss; *Hexagonal* of Naumann; *Monotrimetric* of Hausmann.

ORTHORHOMBIC. *Prismatic*, or *Orthotype*, of Mohs; *Ein-und-einaxige* of Weiss; *Rhombic* and *Anisometric* of Naumann; *Trimetric* and *Orthorhombic* of Hausmann; *Trimetric* of earlier editions of Dana's System.

MONOCLINIC *Hemiprismatic* and *Hemiorthotype* of Mohs; *Zwei-und-eingliedrige* of Weiss; *Monoclinohedral* of Naumann; *Clinorhombic* of v. Kobell, Hausmann, Des Cloizeaux; *Augitic* of Haidinger; *Oblique* of Miller; *Monosymmetric* of Groth (1876).

TRICLINIC. *Tetarto-prismatic* of Mohs; *Ein-und-eingliedrige* of Weiss; *Triclinohedral* of Naumann; *Clinorhomboidal* of v. Kobell; *Anorthic* of Haidinger and Miller; *Anorthic*, or *Doubly Oblique*, of Des Cloizeaux; *Asymmetric*, of Groth (1876).

As remarked later, some authors prefer to divide the thirty-two symmetry groups into *seven* systems, referring the so-called rhombohedral forms to three equal axes with equal oblique intersections; this is the *trigonal system* of Groth (1896).

24. Each one of the six systems, as will be understood from Art. **21**, embraces several groups differing among themselves in their symmetry. One of these groups is conveniently called the *normal* group, since it is in general the common one, and since further it exhibits the highest degree of symmetry possible for the given system, while the others are lower in grade of symmetry.

It is important to note that the groups comprised within a given system are at once essentially connected together by their common optical characters, and in general separated * from those of the other systems in the same way.

In the paragraphs immediately following, a synopsis is given of the symmetry of the *normal group* of each of the different systems, and also that of one subordinate group of the hexagonal system, which is of so great importance that it is also often conveniently treated as a sub-system even when, as in this work, the forms are referred to the same axes as those of the strictly hexagonal type—a usage not adopted by all authors.

25. Symmetry of the Systems.—With respect to the symmetry of the form, which finds practical expression, as before stated, in the axial relations, the *normal groups* under the different systems are characterized as follows.

I. ISOMETRIC SYSTEM. Three like axial † planes of symmetry (principal planes) parallel to the cubic faces, and fixing by their intersection the crystallographic axes; six like diagonal planes of symmetry, passing through each opposite pair of cubic edges, and hence parallel to the faces of the rhombic dodecahedron.

Further, three like axes of tetragonal symmetry, the cubic or crystallographic axes; four like axes of trigonal symmetry, the octahedral axes; and six like axes of binary symmetry, the dodecahedral axes. There is also obviously a center of symmetry.‡ These relations are illustrated by Fig 28; also by Fig. 41; further by Figs. 70 to 110.

---

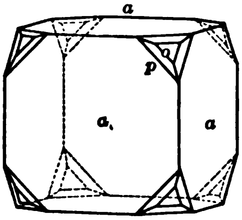
*Crystals of the tetragonal and hexagonal systems are alike in being optically uniaxial; but the crystals of all the other systems have distinguishing optical characters.

† Two planes of symmetry are said to be *like* when they divide the ideal crystal into halves which are identical to each other; otherwise, they are said to be *unlike*. Axes of symmetry are also like or unlike. If a plane of symmetry includes two of the crystallographic axes, it is called an *axial plane* of symmetry. If the plane includes two or more like axes of symmetry, it is called a *principal plane* of symmetry; also an axis of symmetry in which two or more like planes of symmetry meet is a *principal axis* of symmetry.

‡ In describing the symmetry of the different groups, here and later, the center of symmetry is ordinarily not mentioned when its presence or absence is obvious.

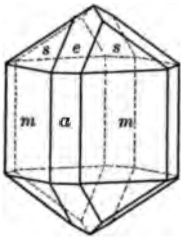
II. Tetragonal System. Three axial planes of symmetry: of these two are like planes intersecting at 90° in a line which is the vertical crystallographic axis, and the third plane (a principal plane) is normal to them and hence contains the lateral axes. There are also two diagonal planes of symmetry, intersecting in the vertical axis and meeting the two axial planes at angles of 45°.

28.



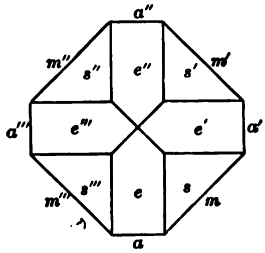
Galena.

29.



Rutile.

30.

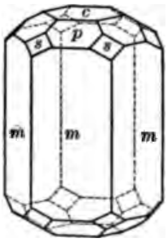


Rutile.

Further, there is one axis of tetragonal symmetry, a principal axis; this is the vertical crystallographic axis. There are also in a plane normal to this four axes of binary symmetry—like two and two—those of each pair at right angles to each other. Fig. 29 shows a typical tetragonal crystal, and Fig. 30 a basal projection of it, that is, a projection on the principal plane of symmetry normal to the vertical axis. See also Fig. 42 and Figs. 149–171.

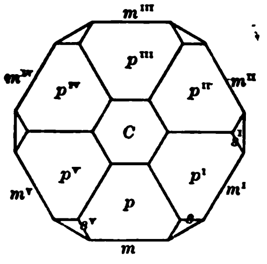
III. Hexagonal System. In the *Hexagonal Division* there are four axial planes of symmetry; of these three are like planes meeting at angles of 60°, their intersection-line being the vertical crystallographic axis; the fourth plane (a principal plane) is at right angles to these. There are also three other diagonal planes of symmetry meeting the three of the first set in the vertical axis, and making with them angles of 30°.

31.



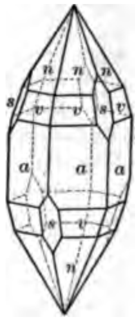
Beryl.

32.



Beryl.

33.

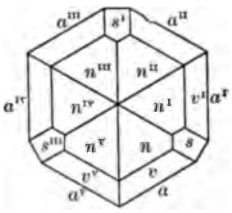


Corundum.

Further, there is one principal axis of hexagonal symmetry; this is the vertical crystallographic axis; at right angles to it there are also six binary axes. The last are in two sets of three each. Fig. 31 shows a typical hexagonal crystal, and Fig. 32 a basal projection of the same. See also Fig. 43 and Figs. 195–209.

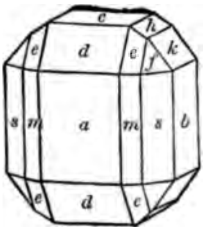
In the *Trigonal* or *Rhombohedral Division* of this system there are three like planes of symmetry intersecting at angles of 60° in the vertical axis. Further, the forms belonging here have a vertical principal axis of trigonal symmetry, and three horizontal axes of binary symmetry, diagonal in position to the crystallographic axes. Fig. 33 shows a typical rhombohedral crystal, and Fig. 34 a basal projection. See also Figs. 226–252.

34.



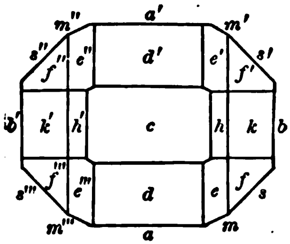
Corundum.

35.



Chrysolite.

36.

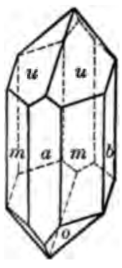


Chrysolite.

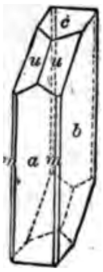
IV. Orthorhombic System. Three unlike planes of symmetry meeting at 90°, and fixing by their intersection-lines the position of the crystallographic axes. Further, three unlike axes of binary symmetry coinciding with the last-named axes. Fig. 35 shows a typical orthorhombic crystal, and Fig. 36 a basal projection. See also Fig. 44 and Figs. 275–303.

V. Monoclinic System. One plane of symmetry which contains two of the crystallographic axes. Also one axis of binary symmetry, normal to this plane and coinciding with the third crystallographic axis. See Figs. 37–39; also Fig. 45 and Figs. 312–327.

37.

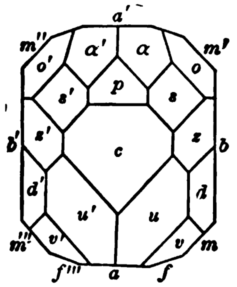


38.



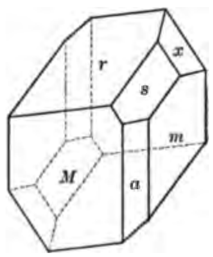
Pyroxene.

39.



Pyroxene.

40.



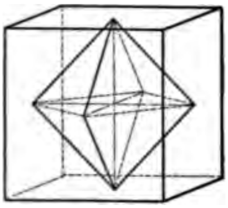
Axinite.

VI. Triclinic System. No plane and no axis of symmetry, but symmetry solely with respect to the central point. Fig. 40 and Fig. 46 show typical triclinic crystals. See also Figs. 333–341.

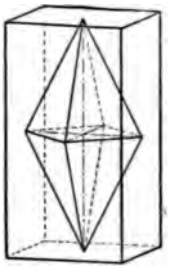
26. The relations of the normal groups of the different systems are further illustrated both as regards the crystallographic axes and symmetry by the accompanying figures, 41–46. The exterior form is here that bounded by faces each of which is parallel to a plane through two of the crystallographic axes indicated by the central broken lines. Further, there is shown, within this, the combination of faces each of which joins the extremities of the unit lengths of the axes.

The full understanding of the subject will not be gained until after a study of the forms of each system in detail. Nevertheless the student will do well to make himself familiar at the outset with the fundamental relations here illustrated.

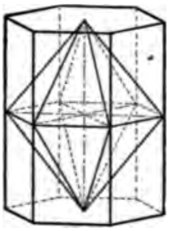
41.



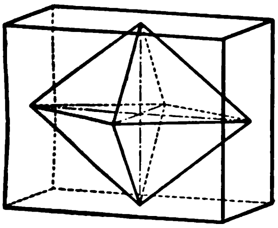
42.



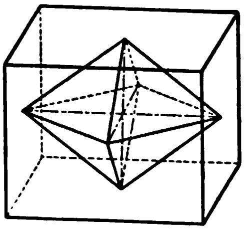
43.



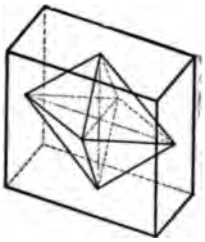
44.



45.



46.



It will be shown later that the symmetry of the different groups can be most clearly and easily exhibited by the use of the spherical projection explained in Art. 39 *et seq.*

27. Models.—Glass (or transparent celluloid) models illustrating the different systems, having the forms shown in Figs. 41–46, will be very useful to the student, especially in learning the fundamental relations as regards symmetry. They should show within the crystallographic axes, and by colored threads or wires the outlines of one or more simple forms. Models* of wood are also made in great variety and perfection of form: these are indispensable to the student in mastering the principles of crystallography.

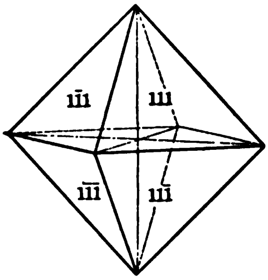
28. So-called Holohedral and Hemihedral Forms.—It will appear later that each crystal form† of the normal group in a given system embraces *all* the faces which have a like geometrical position with reference to the crystallographic axes; such a form is said to be *holohedral* (from ὅλος and ἕδρα, face). On the other hand, under the groups of lower symmetry, a certain form, while necessarily having all the faces which the symmetry allows, may yet have but *half* as many as the corresponding form of the normal group; these half-faced forms are sometimes called on this account *hemihedral*. Furthermore, it will be seen that, in such cases, to the given holohedral form there correspond two similar and complementary hemihedral forms, called respectively plus and minus (or right and left), which together embrace all of its faces.

---

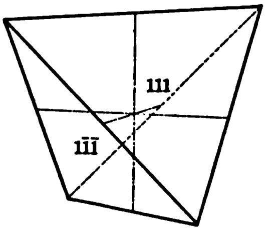
* Models can be obtained from Dr. F. Krantz in Bonn, Germany.
† The use of the word *form* is defined in Art. 36.

A single example will help to make the above statement intelligible. In the normal group of the isometric system, the octahedron (Fig. 47) is a "holohedral" form with all the possible faces—eight in number—which are alike in that they meet the axes at equal distances. In the tetrahedral group of the same system, the forms are referred to the same crystallographic axes, but the symmetry defined in Art. 19 (and more fully later) calls for but four similar faces having the position described. These yield a four-faced, or "hemihedral," form, the tetrahedron. Figures 48 and 49 show the plus and minus tetrahedron, which together, it will be seen, embrace all the faces of the octahedron, Fig. 47.

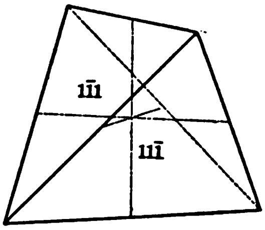
47.



48.



49.

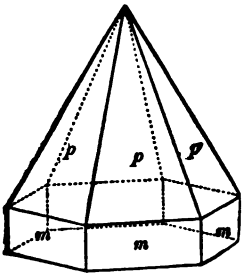


In certain groups of still lower symmetry a given crystal form may have but *one-quarter* of the faces belonging to the corresponding normal form, and, after the same method, such a form is sometimes called *tetartohedral.*

The development of the various possible kinds of hemihedral (and tetartohedral) forms under a given system has played a prominent part in the crystallography of the past, but it leads to much complexity and is distinctly less simple than the direct statement of the symmetry in each case. The latter method is systematically followed in this work, and the subject of hemihedrism is dismissed with the brief (and incomplete) statements of this and the following paragraphs.

29. Hemimorphic Forms.—In several of the systems, forms occur under the groups of lower symmetry than that of the normal group which are characterized by this: that there is no transverse plane of symmetry, but the faces present are only those belonging to one extremity of an axis of symmetry (and crystallographic axis). Such forms are conveniently called *hemimorphic* forms. A simple example under the hexagonal system is given in Fig. 50. It is obvious that hemimorphic forms have no center of symmetry.

50.



Zincite.

30. Molecular Networks.—Much light has recently been thrown upon the relations existing between the different types of crystals, on the one hand, and of these to the physical properties of crystals, on the other, by the consideration of the various possible methods of grouping of the molecules of which the crystals are supposed to be built up. This subject, very early treated by Haüy and others (including J. D. Dana), was discussed at length by Frankenheim and later by Bravais. More recently it has been extended and elaborated by Sohncke, Wulff, Schönfliess, Fedorow, Barlow, and others.*

All solid bodies, as stated in Art. 7, are believed to be made up of definite physical units, called the physical, or crystal, molecules. Of the form of the molecules nothing is definitely known, and though theory has something to say about their size, it is enough here to understand that they are almost infinitely small, so small that the surface of a solid—*e.g.* of a crystal—may appear to the touch and to the eye, even when assisted by a powerful microscope, as perfectly smooth.

---

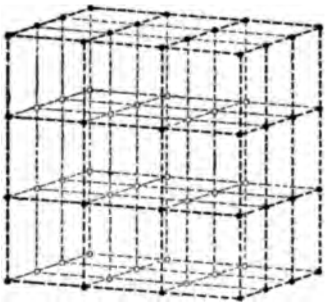
* See the literature following Art. 32.

The molecules are further believed to be not in contact but separated from one another—if in contact, it would be impossible to explain the motion to which the sensible heat of the body is due, or the transmission of radiation (radiant heat and light) through the mass by the wave motion of the ether, which is believed to penetrate the body.

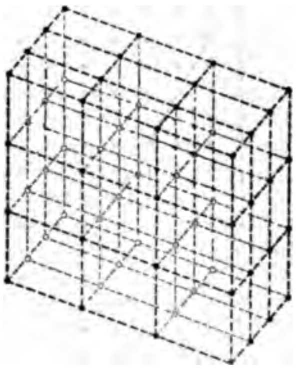
When a body passes from the state of a liquid or a gas to that of a solid, under such conditions as to allow perfectly free action to the forces acting between the molecules, the result is a crystal of some definite type as regards symmetry. The simplest hypothesis which can be made assumes that the form of the crystal is determined by the way in which the molecules group themselves together in a position of equilibrium under the action of the intermolecular forces.

As, however, the forces between the molecules vary in magnitude and direction from one type of crystal to another, the resultant grouping of the molecules must also vary, particularly as regards the distance between them and the angles between the planes in which they lie. This may be simply represented by a series of geometrical diagrams, showing the hypothetical groupings of points which are strictly to be regarded as the centers of gravity of the molecules themselves. Such a grouping is named a *network*, or point-system, and it is said to be *regular* when it is the same for all parallel lines and planes, however they be taken. For the fundamental observed fact, true in all simple crystals, that they have like physical properties in all parallel directions, leads to the conclusion that the grouping of the molecules must be the same about each one of them (or at least about each unit group of them), and further the same in all parallel lines and planes.

51.



52.



The subject may be illustrated by Figs. 51, 52 for two typical cases, which are easily understood. In Fig. 51 the most special case is represented where the points are grouped at equal distances, in planes at right angles to each other. The structure in this case obviously corresponds in symmetry to the cube described in Arts. **15** and **16**, or, in other words, to the normal group of the isometric system. Again, in Fig. 52, the general case is shown where the molecules are unequally grouped in the three directions, and further these directions are oblique. The symmetry is here that of the normal group of the triclinic system.

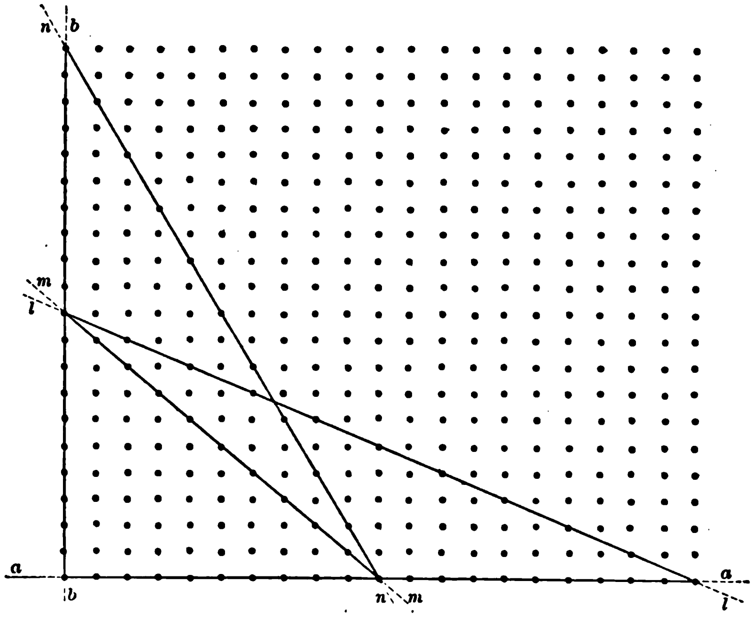
If, in each of these cases, the figure be bounded by the simplest possible arrangement of eight points, the result is an *elementary parallelopiped*, which obviously defines the molecular structure of the whole. In the grouping of these parallelopipeds together, as described, it is obvious that in whatever direction a line be drawn through them, the points (molecules) will be spaced alike along it, and the grouping about any one of these points will be the same as about any other.

31. Certain important conclusions can be deduced from a consideration of such regular molecular networks as have been spoken of, which will be enumerated here though it is impossible to attempt a full explanation.

(1) The prominent crystalline faces must be such as include the largest number of points, that is, those in which the points are nearest together.

Thus in Fig. 53, which represents a section of a network conforming in symmetry to the structure of a normal orthorhombic crystal, the common crystalline faces would be expected to be those having the position *bb*, *aa*, *mm*, then *ll*, *nn*, and so on. This is found to be true in the study of crystals, for the common forms are, in nearly all cases, those whose position bears some simple relation to the assumed axes; forms whose position is complex are usually present only as small faces on the simple predominating forms, that is, as modifications of them. So-called *vicinal* forms, that is, forms taking the place

53.



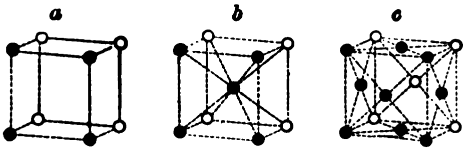
of the simple fundamental forms to which they approximate very closely in angular position, are exceptional.

(2) When a variety of faces occur on the same crystal, the numerical relation existing between them (that which fixes their position) must be rational and, as stated in (1), a simple numerical ratio is to be expected in the common cases. This, as explained later, is found by experience to be a fundamental law of all crystals. Thus in Fig. 53, starting with a face meeting the section in *mm*, *ll* would be a common face, and for it the ratio is 1:2 in the directions *b* and *a*; *nn* would be also common with the ratio 2:1.

(3) If a crystal shows the natural easy fracture, called cleavage, due to a minimum of cohesion, the cleavage surface must be a surface of relatively great molecular crowding, that is, one of the common or fundamental faces. This follows (and thus gives a partial, though not complete, explanation of cleavage) since it admits of easy proof that that plane in which the points are closest together is farthest separated from the next molecular plane. Thus in Fig. 53 compare the distance separating two adjoining planes parallel to *bb* or *aa*; then two parallel to *mm*, *ll*, *nn*, etc. Illustrations of the above will be found under the special discussion of the subject of cleavage.

32. Kinds of Molecular Groupings.—The discussion on the basis just described shows that there are fourteen possible types of arrangement of the molecules. These agree as to their symmetry with the seven groups defined in Art. 25 as representing respectively the normal groups of the six systems with also that of the trigonal (or the rhombohedral) division of the hexagonal system. Of the fourteen, three groupings belong to the isometric system (these are shown, for sake of illustration, in Fig. 54, *a*, *b*, *c*, from Groth); two to the tetragonal; one each to the hexagonal and the rhombohedral; four to the orthorhombic system; two to the monoclinic, and one to the triclinic.

54.



In its simplest form, as above outlined, the theory fails to explain the existence of the groups under the several systems of a symmetry lower than that of the normal group. It has been shown, however, by Sohncke and later by Fedorow, Schönflies and Barlow, that the theory admits of extension. The idea supposed by Sohncke is this: that, instead of the simple form shown, the network may consist of a double system, one of which may be conceived of as having a position relative to the other (1) as if pushed to one side, or (2) as if rotated about an axis, or finally (3) as if both rotated as in (2) and displaced as in (1). The complexity of the subject makes it impossible to develop it here. It must suffice to say that with this extension Sohncke concludes that there are 65 possible groups. This number has been further extended to 230 by the other authors named, but it still remains true that these fall into 32 distinct types as regards symmetry, and thus all the observed groups of forms among crystals, described under the several systems, have a theoretical explanation.

Literature.—A complete understanding of this subject can only be gained by a careful study of the many papers devoted to it, a partial list of which is added below. Further references particularly to the early literature are given in Sohncke's work (see below). An excellent and very clear summary of the whole subject is given by Groth in the third edition of his Physikalische Krystallographie, 1895.

Early papers:

Frankenheim. De Crystallorum Cohæsione, 1829; also in Baumgartner's Zeitschrift für Physik, **9**, 94, 194, 1831. Die Lehre von der Cohäsion, Breslau, 1835. Ueber die Anordnung der Molecüle im Krystall; Pogg., **97**, 337, 1856.

Hessel. Article 'Krystall' in Gehler's physikal. Wörterbuch, 5, 1830 (see Sohncke, Zs. Kryst., **18**, 486).

Bravais. Mémoire sur les systèmes formes par des points distribués régulièrement sur un plan ou dans l'espace, Paris, 1850; and in Études cristallographiques. Paris, 1866.

Gadolin. Act. Soc. Fennicæ, **9**, 1, 1871 (republished in Ostwald's Klassiker d. exakten Wissenschaften, No. 75).

Later works and papers:

Barlow. Nature, **29**, 186, 205, 1883; Zs. Kryst., **23**, 1, 1894; **25**, 86, 1895; Min. Mag., **11**, 119, 1896, and Zs. Kryst., **27**, 449, 468, 1896; R. Dublin Soc., **8**, 527, 1897, and Zs. Kryst., **29**, 433, 1898.

Curie. Bull. Soc. Min., **7**, 89, 418, 1884.

Fedorow. Zs. Kryst., **20**, 25, 259; **24**, 209, 1894; **25**, 113, 1895; **28**, 36, 232, 468, 1897.

Goldschmidt. Zs. Kryst., **28**, 1, 414, 1897.

Kelvin. Proc. R. Soc. Edinb., **16**, 693, 1888; Proc. Roy. Soc., **55**, 1, 1894.

Minnegerode. Nachr. Ges. Göttingen, 1884; Jb. Min. Beil.-Bd., **5**, 145, 1887.

Schönflies. Nachr. Ges. Göttingen, 483, 1888; 239, 1890. Also as a separate work, Krystallsysteme und Krystallstructur, Leipzig, 1891.

Sohncke. Die Gruppirung der Moleküle in den Krystallen, Pogg. Ann., **132**, 75, 1867. Also Wied. Ann., **16**, 489, 1882; Zs. Kryst., **13**, 209, 214, 1887; **14**, 417, 426, 1888; **18**, 486, 1890. Entwickelung einer Theorie der Krystallstructur, Leipzig, 1879.

Viola. Zs. Kryst., **27**, 1, 1896; **28**, 452; **29**, 1, 234, 1897.

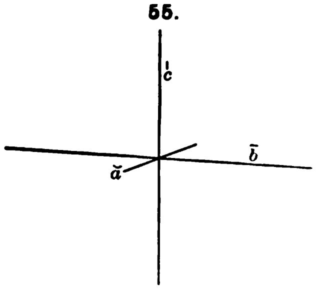
L. Wulff. Zs. Kryst., **13**, 503, 1887; **15**, 366, 1889; **18**, 174, 1890.

Wülfing. For title see p. 2.

GENERAL MATHEMATICAL RELATIONS OF CRYSTALS.

33. Axial Ratio, Axial Plane.—The crystallographic axes have been defined (Art. 22) as certain lines, usually determined by the symmetry, which are used in the description of the faces of crystals, and in the determination of their position and angular inclination. With these objects in view, certain lengths of these axes are assumed as units to which the occurring faces are referred.

55.



The axes are, in general, lettered a, b, c, to correspond to the scheme in Fig. 55. To aid the memory, the letters may be further distinguished; as $\overset{|}{c}$ (vertical axis); $\breve{a}, \bar{b}$ (shorter and longer lateral axes), etc.

If two of the axes are equal, they are designated $a, a, \overset{|}{c}$; if three, a, a, a. In one system, the hexagonal, there are four axes, lettered $a, a, a, \overset{|}{c}$.

Further, in the systems other than the isometric, one of the lateral axes is taken as the unit to which the other axes are referred; hence the lengths of the axes express strictly the *axial ratio*. Thus for sulphur (orthorhombic, see Fig. 57) the axial ratio is

$$\breve{a} : \bar{b} : \overset{|}{c} = 0{\cdot}8131 : 1 : 1{\cdot}9034.$$

For rutile (tetragonal) it is

$$a : \overset{|}{c} = 1 : 0{\cdot}64415, \quad \text{or,} \quad \text{simply, } \overset{|}{c} = 0{\cdot}64415.$$

The plane of any two of the axes is called an *axial plane*, and the space included by the three axial planes is an *octant*, since the total space about the center is thus divided by the three axes into eight parts. In the hexagonal system, however, where there are three lateral axes, the space about the center is divided into 12 parts, or *sectants*.

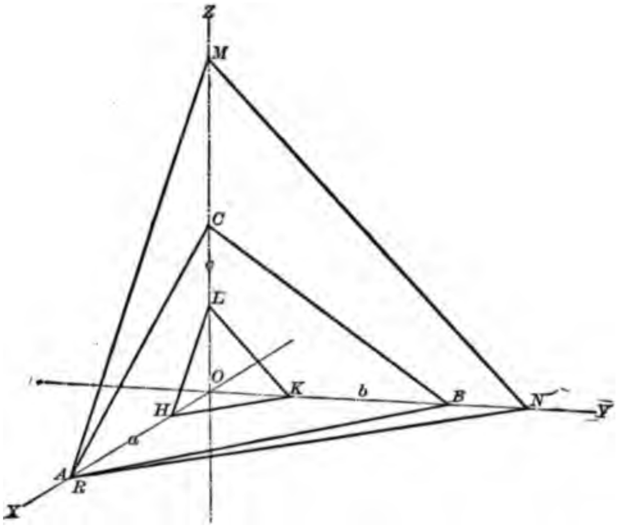
34. Parameters, Symbol.—The *parameters* of a plane are its intercepts on the assumed axes. The *symbol* expresses, often in abbreviated form, the relation of these intercepts to certain lengths of the axes taken as units.

For example, in Fig. 56 let the lines *OX*, *OY*, *OZ* be taken as the directions of the crystallographic axes, and let *OA*, *OB*, *OC* represent the unit lengths, designated (always in the same order) by the letters *a*, *b*, *c*. Then the parameters for the plane (1) *HKL* are *OH*, *OK*, *OL*; for the plane (2) *RNM* they are *OR*, *ON*, *OM*. But in terms of the unit lengths these are, respectively,

$$(1)\quad \frac{1}{4}a : \frac{1}{3}b : \frac{1}{2}c, \qquad \text{or} \qquad (2)\quad 1a : \frac{4}{3}b : 2c.$$

These two expressions are *identical*, since the two planes *HKL*, *MNR* are parallel and hence crystallographically the same. Obviously each of the above expressions may be changed into the other by multiplying (or dividing) by 4.

56.



It will be noted that in (1) the numerators of the fractional numbers expressing the relation to the axes are all unity; while in (2) the number referring to one of the lateral axes (*a*) is made unity. The significance of this distinction will appear at once.

The general expression for any plane referred to these axes, written after the same method, will be

$$(1)\quad \frac{1}{h}a : \frac{1}{k}b : \frac{1}{l}c, \qquad \text{or} \qquad (2)\quad 1a : nb : mc.$$

Here in (1) the numbers, or *indices*, *hkl* (in the case above, 432) constitute the *symbol* after the method of Miller (1839; earlier developed by Whewell and Grassmann).

The second form (2) is the symbol essentially as early written by Weiss. This last was contracted by Naumann to *mPn* (*mOn* in the isometric system), the axes being omitted from the expression and the order reversed; the same with the omission of the *P* (or *O*), *m-n*, is adopted in Dana's System of Mineralogy, in the last edition (1892) of which work, however, the Miller symbols are given the preference.

In the hexagonal system there are assumed four axes, three of them lateral axes. Corresponding to this, in the symbols after the method of Miller as adapted by Bravais, there are four indices, *hkil*. The relation of these to the axes is the same as in the other cases, as explained under the hexagonal system.

The following are other examples of planes with the symbols written after the two methods given. It will be seen that the respective expressions under (1) and (2) are identical.

(1)	Miller's Symbol.		(2)	Naumann's Symbol.
$\frac{1}{2}a : \frac{1}{2}b : \frac{1}{1}c$	221	or	$1a : 1b : 2c$	$2P$ or 2
$\frac{1}{2}a : \frac{1}{1}b : \frac{1}{2}c$	212	"	$1a : 2b : 1c$	$P2$ or 1-2
$\frac{1}{2}a : \frac{1}{0}b : \frac{1}{1}c$	201	"	$1a : \infty b : 2c$	$2P\infty$ or 2-*i*
$\frac{1}{2}a : \frac{1}{1}b : \frac{1}{0}c$	210	"	$1a : 2b : \infty c$	$\infty P2$ or *i*-2
$\frac{1}{1}a : \frac{1}{0}b : \frac{1}{0}c$	100	"	$1a : \infty b : \infty c$	$\infty P\infty$ or *i-i*

If the axial values are measured behind for the axis *a*, to the left for *b*, or below for *c*, they are called negative, and a minus sign is placed *over* the corresponding number of the Miller symbols; as,

	Miller.		Miller.
$-\frac{1}{2}a : -\frac{1}{2}b : \frac{1}{2}c$	$\bar{2}\bar{2}1$	$-\frac{1}{2}a : \frac{1}{0}b : \frac{1}{1}c$	$\bar{2}01$

It is sometimes stated that Naumann's symbols are the more easy of comprehension because more readily referred to the axes, and this is in a measure true. If the student, however, will accustom himself to think of the Miller symbols in the form given above, that is, always as the denominators of the fractional values of the axes whose numerators are unity, he will never have any trouble in seeing the position of a given plane relatively to the axes. He must remember that the order is always that given above, *h*, *k*, and *l* referring respectively to the axes *a*, *b*, and *c*; moreover, he will note that a zero, 0, always means that the given plane is parallel to the axis to which it refers, since $\frac{1}{0} = \infty$.

With the symbols of Naumann, the *m*, written first, always refers to the vertical axis, while the *n*, which follows, and is always greater than unity, refers to one of the lateral axes, the other being made unity. To which lateral axis the *n* belongs is often indicated by a mark over the *n* ($\bar{n}$, or $\breve{n}$, or $\grave{n}$), or attached to the *P* as explained under the different systems. When $m = 1$, it is omitted before the *P* or *O* (but not so when the *P* is dropped); and when $n = 1$, it is omitted in all cases.

Other systems of symbols, besides the two explained, have also been or still are in use, as those of Weiss, of Mohs and Haidinger, Hausmann, Lévy, Goldschmidt, and others.

Of these the symbols of Weiss are essentially those already given (under 2, p. 21) which, abbreviated (and inverted in order), were adopted by Naumann. The symbols of Lévy have been extensively used by the French school of mineralogists. A very full explanation of all the different systems, as of that recently devised by himself, is given in Goldschmidt's Index (1886–1891). Transformation equations for the important cases, are given by Groth (Phys. Kryst.), Mallard (Crist., vol. 1), Liebisch (Kryst.), and others ; see p. 2.

35. Law of Rational Indices.—The study of crystals has established the general law that the ratios between the intercepts on the axes for any face on a crystal to those of any other face can always be expressed by rational numbers. These ratios may be 1 : 2, 2 : 1, 2 : 3, 1 : 0 (∞ : 1), etc., but never $1 : \sqrt{2}$, etc. Hence the values of *hkl* in the Miller symbols must always be either *whole numbers or zero*, and similarly the *m* and *n* of Naumann's symbols may be whole numbers or fractions, or infinity.

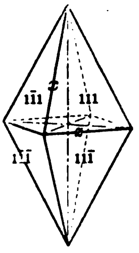
If the form whose intercepts on the axes *a*, *b*, *c* determine their assumed unit lengths—the *unit form* as it is called—is well chosen, these numerical values of the indices are in most cases very simple. In the Miller symbols, 0 and the numbers from 1 to 6 are most common.

The above law, which has been established as the result of experience, in fact follows from the consideration of the molecular structure as hinted at in an earlier paragraph (Art. 31).

The law of rational indices finds an illustration later under the isometric system. It is stated there that three of the five regular solids of geometry, viz., the cube, octahedron, and the regular triangular pyramid (crystallographically the tetrahedron) all occur among crystals; the regular pentagonal dodecahedron and icosahedron, on the contrary, are impossible forms. This is true because the ratios of their intercepts on the axes for such forms would be irrational; thus for the regular dodecahedron the ratio would be $1 : \frac{1+\sqrt{5}}{2}$. There are, it is true, two forms respectively twelve-sided and twenty-sided which approximate to these regular solids, but their faces in the first case are not all regular pentagons, and in the second they are not all regular triangles. In the latter case it will be seen that the twenty faces in fact belong to two distinct forms, eight of one and twelve of the other.

36. Form.—A *form* in crystallography includes *all* the faces which have a like position relative to the planes, or axes, of symmetry. The full meaning of this will be appreciated after a study of the several systems. It will be seen that in the most general case, that of a form having the symbol (*hkl*), whose planes meet the assumed unit axes at unequal lengths, there must be forty-eight like faces in the isometric system* (see Fig. 101), twenty-four in the hexagonal (Fig. 201), sixteen in the tetragonal (Fig. 166), eight in the orthorhombic (Fig. 57), four in the monoclinic, and two in the triclinic. In the first four systems the faces named yield an enclosed solid, and hence the form is called a *closed form;* in the remaining two systems this is not true, and such forms in these and other cases are called *open forms.* Fig. 275 shows a crystal bounded by three pairs of unlike faces; each pair is hence an open form. Figs. 58–61 show open forms.

57.



The *unit or fundamental form* is one where parameters correspond to the assumed unit lengths of the axes. Fig. 57 shows the unit pyramid of sulphur whose symbol is (111); it has eight similar faces, the position of which determines the ratio of the axes given in Art. 33.

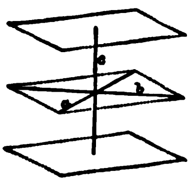
---

* The normal group is referred to in each case.

The forms in the isometric system have special individual names, given later. In the other systems certain general names are employed which may be briefly mentioned here. A form whose faces are parallel to two of the axes* is called a *pinacoid* (from πίναξ, a board, it is shown in Fig. 58. One whose faces are parallel to the vertical axis but meet both the lateral axes is called a *prism*, as Fig. 59. If the faces are parallel to one lateral axis only, it is a *dome* (Figs. 60, 61). If the faces meet all the axes, the form is a *pyramid* (Fig. 57); this name is given even if there is only one face belonging to the form.

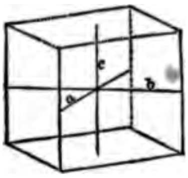
In Fig. 62, *a* (100), *b* (010), *c* (001) are pinacoids; *m* (110), *s* (120) are prisms; *d* (101), also *h* (011), *k* (021) are domes; all these are open forms. Finally, *e* (111), *f* (121) are pyramids, and in this case they are closed forms. The relation existing in each of these cases between the symbol and the position of the faces to the axes should be carefully studied.

58.



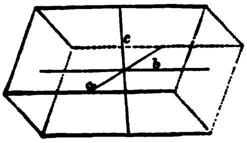
Basal Pinacoid.
(001)

59.



Prism.
(110)
(*hk*0)

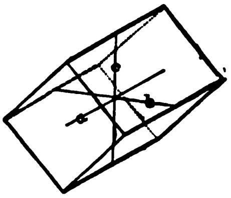
60.



Domes.

(101)
(*h*0*l*)

61.



(011)
(0*kl*)

As shown in the above cases, the symbol of a *form* is usually included in parentheses, as (111), (100); or it may be in brackets [111] or { 111 }. If the symbol is written without parenthesis, as 111, it usually refers to a single face of the form only. Note also that with the Miller symbols, each face of a given form has its own individual symbol.

37. Zone.—A zone includes a series of faces on a crystal whose intersection-lines are mutually parallel to each other and to a common line drawn through the center of the crystal, called the zone-axis. This parallelism means simply that the parameters of the given faces have a constant ratio for two of the axes. Some simple numerical relation exists, in every case, between all the faces in a zone, which is expressed by the *zonal equation*. The faces *a*, *m*, *s*, *b* (Fig. 62) are in a zone; also, *b*, *k*, *h*, *c*, etc.

If a face of a crystal falls simultaneously in two zones, it follows that its symbol is fixed and can be determined from the two zonal equations, without the measurement of angles. Further, it can be proved that the face corresponding to the intersection of two zones is always a possible crystal face, that is, one having rational values for the indices which define its position.

In many cases the zonal relation is obvious at sight, but it can always be determined, as shown in Arts. **43**, **44**, by an easy calculation.

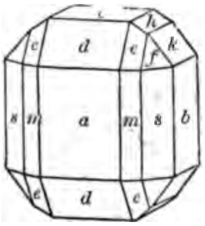
Illustrations will be given after the methods of representing a crystal by horizontal and spherical projections have been explained.

38. Horizontal Projections.—In addition to the usual perspective figures of crystals, projections on the basal plane (or more generally the plane normal to the prismatic zone) are very conveniently used. These give in fact a map of the crystal as viewed from above looking in the direction of the axis of the prismatic zone. Figs. 30, 32, 34 give simple examples; also Fig. 63 a projection of Fig. 62, both repeated from p. 16. In these the successive faces may be indicated by accents, as in Fig. 63, passing around in the direction of the axes *a*, *b*, *a′*, that is, counter-clockwise. On the construction of these projections see the Appendix A.

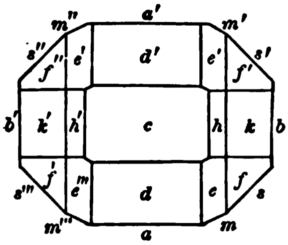
---

* In the tetragonal system the form (100) is, however, called a prism and (101) a pyramid.

62.

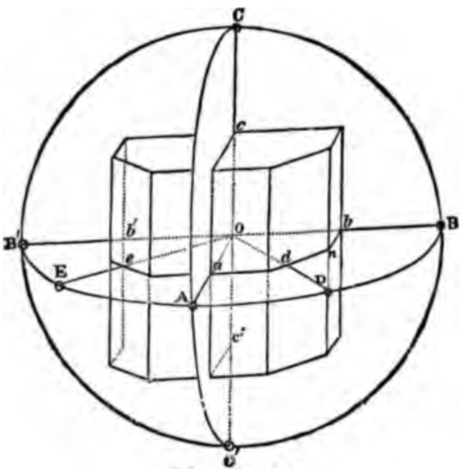


63.



39. Spherical Projections.—The study of actual crystals, particularly as regards the angular and zonal relations of their faces, is much facilitated by the use of the *spherical projection*. In this the position of each face is represented by a point called its *pole*, where a normal drawn to it from the center and produced meets the surface of the sphere. The symbols after Miller are immediately connected with this projection, and by means of it all ordinary calculations can be performed in a very simple manner. Fig. 65 shows a spherical projection of the orthorhombic crystal, Fig. 62.

64.



After Brezina.

If the center of a crystal, that is, the point of intersection of the crystallographic axes, be taken as the center of a sphere, and normals be drawn from it to the successive faces of the crystal, the points, where they meet the surface of the sphere, will be, as before defined, the *poles* of the respective faces. For example, in Fig. 64, the common center of the crystal and sphere is at O, the normal to the face *b* meets the surface of the sphere at B, of *b′* at B′, of *d* and *e* at D and E respectively, and so on. These poles evidently determine the position of the face in each case.

It is obvious that the pole of the face *b′* (0$\bar{1}$0) opposite *b* (010) will be at the opposite extremity of the diameter of the sphere, and so in general for (120) and (1$\bar{2}$0), etc. It is seen also that all the poles, or normal points, of faces in the same *zone*, that is, faces whose intersection-lines are parallel, are in the same great circle, for instance *B*(010), *D*(110), *A*(100), *E*(1$\bar{1}$0), and so on.

It is customary in the use of the sphere to regard it as projected upon a horizontal plane, usually that normal to the prismatic zone, so that, as in Fig. 65, the poles of the prismatic faces lie in the circumference of the circle, and those of the other faces within it. The eye being supposed to be situated at the opposite extremity of the diameter of the sphere normal to this plane, the great circles then appear either as arcs of circles, or as straight lines, *i.e.*, diameters.

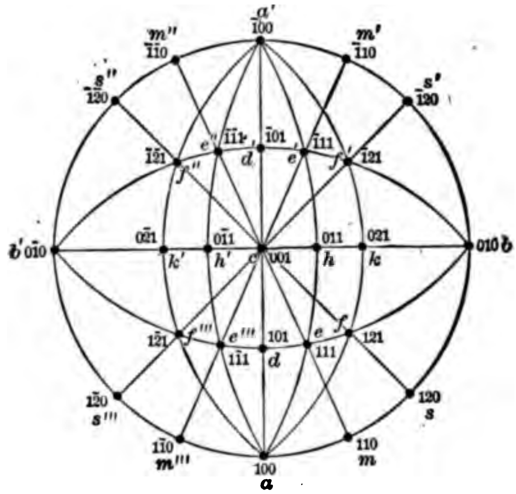
It will be further obvious from Fig. 64 that the arc BD, between the poles of *b* and *d*, measures an angle at the center (BOD), which is the *supplement* of the actual interior angle *bnd* between the two faces; and this is true in general.

40. Construction of the Spherical Projection.—Since in the method ordinarily followed the poles of the prismatic faces lie in the circumference of the circle, their position is fixed at once by the angles laid off, *e.g.* from 100, with a protractor. Further, the distances of the poles of all faces measured from the center of the circle (which, when the vertical axis is at right angles to those in the lateral plane, is the pole of the base 001) are proportional to *the tangents of half the angles*. For example, to construct the spherical projection of Fig. 62, first draw the circle, and lay off on the circumference, from a point taken as 100, the angular distances characteristic of this species (chrysolite):

am, $100 \wedge 110 = 24^\circ\ 58'$; *as*, $100 \wedge 120 = 42^\circ\ 58'$; *ab*, $100 \wedge 010 = 90^\circ$.

The position of the poles of the faces *a* (100), *m* (110), *s* (120), *b* (010) are thus fixed. The poles of the other faces of these forms are obviously fixed, *a′*, *m′*, *s′*, *b′*, *m″*, *s″*, *m‴*, *s‴*, by the symmetry. Again, to find the pole of *d* (101), which lies on the great circle, or zone, *a* (100), *c* (001), *a′* ($\bar{1}00$) (for which $k = 0$): since *c* (001) ∧ *d* (101) = 51° 38′, the distance *cd* is proportional to the tangent of ½(51° 38′) or 25° 46½′, that is, 0.483 of the radius *ca*. Similarly for *h* (011) and *k* (021) on the zone-circle *c* (001), *b* (010), since *ch* (001 ∧ 011) = 30° 28½′ and *ck* (001 ∧ 021) = 49° 38′, the distances are proportional to the tangents of half these angles respectively. So also from the angles *ce* (001 ∧ 111) = 54° 15′ and *cf* (001 ∧ 121) = 59° 50½′ the distances on the corresponding zone-circles, *c* (001) *m* (110) and *c* (001) *s* (120), may be determined. In practice, however, these last steps are unnecessary; since if the circular arc through *b* (010), *d* (101), *b′* ($0\bar{1}0$) is drawn, it gives the zone-circle for all the faces for which $h = l$; similarly that through *a* (100), *h* (011), *a′* ($\bar{1}00$) give the zone-circle for the planes for which $k = l$, while that through *a* (100), *k* (021), *a′* ($\bar{1}00$) gives the zone-circle for the planes having $k = 2l$. The intersection-points between these last arcs and that first drawn fixes the positions of *e* (111), *f* (121), each of which satisfies the two relations. Further, through these same points must pass the zone-circle *c* (001), *m* (110), for which $h = k$, and *c* (001), *s* (120), for which $k = 2h$, thus giving a check upon the accuracy of the work.

65.



It is obvious from the above explanation that the position of any face, as 431, is fixed by the intersection of either two of the three zone-circles

$$100,\ 031,\ \bar{1}00 \qquad 010,\ 401,\ 0\bar{1}0 \qquad 001,\ 430,\ 00\bar{1}.$$

In general any face, *hkl*, must lie in the three zone-circles

$$100,\ 0kl,\ \bar{1}00, \qquad 010,\ h0l,\ 0\bar{1}0, \qquad 001,\ hk0,\ 00\bar{1}.$$

Some further points in regard to the construction of the spherical projection when the axial intersections are oblique are added in Appendix A.

41. Angles between Faces.—The angles most conveniently used with the Miller symbols, and those given in this work, are the *normal angles*, that is, the angles between the poles or normals to the faces, measured on arcs of great circles joining the poles as shown on the spherical projection. These normal angles are the supplements of the actual interfacial angles, as has been explained.

The relations between these normal angles, for example in a given zone, is much simpler than those existing between the actual interfacial angles. Thus it is always true that, for a series of faces in the same zone, the normal angle between two end faces is equal to the sum of the angles of faces falling between. Thus (Figs. 62, 65) the normal angle of *ab* (100 ∧ 010) is the sum of *am* (100 ∧ 110), *ms* (110 ∧ 120), and *sb* (120 ∧ 010). This relation holds true in all the systems.

Furthermore, it will be seen that, supposing *aca′* (Fig. 65) a plane of symmetry as in the orthorhombic system, the angle 110 ∧ 1$\bar{1}$0, or *am* (Fig. 62), is half the angle 100 ∧ 1$\bar{1}$0 (*mm‴*). Similarly 010 ∧ 120 (*bs*) is half the angle 120 ∧ $\bar{1}$20 (*ss′*); again, 100 ∧ 111 (*ae*) is the complement of half the angle 111 ∧ $\bar{1}$11 (*ee′*) and 010 ∧ 111 (*be*) the complement of half the angle 111 ∧ 1$\bar{1}$1 (*ee‴*).

Here, as throughout this work, the sign ∧ is used to represent the angle between two faces, usually designated by letters.

42. Use of the Spherical Projection to Exhibit the Symmetry.—The symmetry of any one of the crystalline groups may be readily exhibited by the help of the spherical projection, following the notation introduced by Gadolin (1871, see p. 22).

The axes of binary, trigonal, tetragonal, hexagonal symmetry are represented respectively by the following signs: ⬬▲◆⬢. Further, a plane of symmetry is represented by a full line (zone-circle), while a dotted line indicates that the plane of symmetry is wanting. The position of the crystallographic axes is shown by arrows at the extremities of the lines. The pole of a face in the upper half of the crystal (above the plane of projection) is represented by a cross; one below by a circle. If two like faces fall in a vertical zone a double sign is used, a cross within the circle. Figs. 69, 111, 125, etc., give illustrations.

43. General Relations between Planes in the Same Zone.—It may be demonstrated that if on a crystal two faces P (hkl) and R (pqr) lie in the same zone, then the following equation must hold good:

$$\mathrm{u}a \cos XQ + \mathrm{v}b \cos YQ + \mathrm{w}c \cos ZQ = 0,$$

where $\mathrm{u} = kr - lq, \quad \mathrm{v} = lp - hr, \quad \mathrm{w} = hq - kp.$

The letters u, v, w are called the symbol of the zone or great circle PR. Every face (xyz) of this zone must satisfy the equation

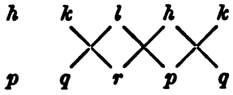
$$\mathrm{u}x + \mathrm{v}y + \mathrm{w}z = 0.$$

If now (uvw) be the symbol of one zone, and (efg) of another intersecting it, then the point of intersection will always be the pole of a possible crystal face. Its indices (hkl) must obviously satisfy two equations similar to (1). These indices are hence equal to

$$h = \mathrm{gv} - \mathrm{fw}, \qquad k = \mathrm{ew} - \mathrm{gu}, \qquad l = \mathrm{fu} - \mathrm{ev}.$$

The application of this principle is extremely simple, and its importance cannot be overestimated.

The zone-symbols can be always obtained by arranging the symbols of the two faces in order, repeating the first two indices and then multiplying according to the following scheme:



Hence $\mathrm{u} = kr - lq; \quad \mathrm{v} = lp - hr; \quad \mathrm{w} = hq - kp.$

44. Examples of Zones and Zonal Relations.—The following are cases in which the zonal equation is seen at once. In Fig. 62, p. 27, the faces *a* (100), *m* (110), *s* (120), *b* (010), form a vertical zone with mutually parallel intersections, since they are alike in position in so far as this: that they are all parallel to the vertical axis; that is, for all faces in this zone it must be true that $l = 0$.

Again, the faces *a* (100), *d* (101), *c* (001) are in zone, all being parallel to a lateral axis $\breve{b}$: hence for them and all others in this zone $k = 0$. Also *b* (010), *k* (021), *h* (011), *c* (001) are in a zone, all being parallel to the axis $\breve{a}$, so that $h = 0$.

Also the faces *f* (121), *e* (111), *d* (10$\bar{1}$), *e''* (1$\bar{1}$1), *f'''* (1$\bar{2}$1) are in a zone, since they have a common ratio for the axes $a : c$. With them, obviously, $h = l$.

The faces *c* (001), *e* (111), *m* (110) are also in a zone, and again *c* (001), *f* (121), *s* (120), though intersections do not happen to be made between *c* and *e* in the one case, and *c* and *f* in the other. For each of these zones it is true that there is a common ratio of the lateral axes, that is, of *h* to *k* in the symbols. For the first it may be shown that $h = k$; for the second, that $2h = k$.

All the relations named may be obtained at once from the above scheme. For example, for the faces *s* (120) and *f* (121) the scheme gives

$$\begin{array}{ccccccccc} 1 & & 2 & & 0 & & 1 & & 2 \\ & & & \times & & \times & & \times & \\ 1 & & 2 & & 1 & & 1 & & 2 \end{array}$$

$$u = 2, \qquad v = \bar{1}, \qquad w = 0; \qquad \therefore 2h - k = 0, \text{ or } 2h = k.$$

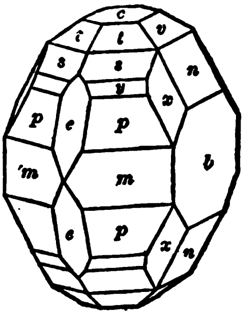
The symbol of a face lying at once in two zones, as stated above, must satisfy the zonal equation of each; these symbols are hence easily obtained either by combining the equations or by a scheme of multiplication like that given above.

For example, in Fig. 66, of sulphur, the face lettered *x* is in the zone (1) with *b* (010) and *s* (113), also in zone (2) with *p* (111) and *n* (011). These zones give, respectively:

$$(1)\quad \begin{array}{ccccccccc} 0 & & 1 & & 0 & & 0 & & 1 \\ & & & \times & & \times & & \times & \\ 1 & & 1 & & 3 & & 1 & & 1 \\ \hline & & 3 & & 0 & & \bar{1} & & \end{array} \qquad\qquad (2)\quad \begin{array}{ccccccccc} 1 & & 1 & & 1 & & 1 & & 1 \\ & & & \times & & \times & & \times & \\ 0 & & 1 & & 1 & & 0 & & 1 \\ \hline & & 0 & & \bar{1} & & 1 & & \end{array}$$

$$u = 3, \quad v = 0, \quad w = \bar{1}. \qquad\qquad e = 0, \quad f = \bar{1}, \quad g = 1.$$

66.



Sulphur.

Hence for (1) the zonal equation is $3h = l$; for (2) $k = l$. Combining these, we obtain $h = 1$, $k = 3$, $l = 3$.

The symbol of the face *x* is, therefore, 133.

The same result is given by multiplying the zonal indices $0\bar{1}1$, $30\bar{1}$, together after the same method, thus:

$$\begin{array}{ccccccccc} 0 & & \bar{1} & & 1 & & 0 & & \bar{1} \\ & & & \times & & \times & & \times & \\ \bar{3} & & 0 & & 1 & & \bar{3} & & 0 \\ \hline & & 1 & & 3 & & 3 & & \end{array}$$

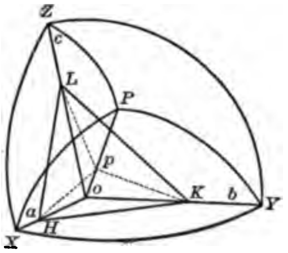
Hence, again, $x = 133$.

This method of calculation belongs to all the different systems. In the hexagonal system, in which there are four indices, one of the three referring to the lateral axes (usually the third) is omitted when the zonal relations are applied. See Art. 160.

45. Methods of Calculation.—In general the angles between the poles can be calculated by the methods of spherical trigonometry from the triangles shown in the sphere of projection (Fig. 65)—which for the most part are right-angled. Certain fundamental relations connect the axes with the elemental angles of the projection; the most important of these are given under the individual systems. Some general relations only are explained here.

46. Relation between the Indices of a Plane and the Angle made by it with the Axes.—When the assumed axes are at right angles to each other they coincide with the normals to the pinacoid faces (100, 010, 001), and consequently meet the spherical surface at their poles. When the axial angles are not 90°, this is no longer true. In all cases, however, the following relation holds good between the cosines of the angles made by a plane, HKL, with the axes:

67.



$$\frac{Op}{OH} = \cos PX; \quad \frac{Op}{OK} = \cos PY; \quad \frac{Op}{OL} = \cos PZ.$$

This is equivalent to

$$\frac{a}{h} \cos PX = \frac{b}{k} \cos PY = \frac{c}{l} \cos PZ.$$

This equation is fundamental, and several of the relations given beyond are deduced from it.

The most useful application is that when the axial angles are 90°; then X, Y, Z are the poles of 100, 010, 001, respectively. Also if the plane HKL is taken as a face of the unit pyramid, that is, if its intercepts on the axes are taken as the unit lengths

$$OH = a, \qquad OK = b, \qquad OL = c.$$

Then the lines HK, HL, KL give also the intersections of the planes 110, 101, 011 on the three axial planes, and their poles are hence at the points fixed by normals to these lines drawn from O. It will be obvious from this figure, then, that the following relations hold true:

$$\tan (100 \wedge 110) = \frac{a}{b};$$

$$\tan (001 \wedge 101) = \frac{c}{a};$$

$$\tan (001 \wedge 011) = \frac{c}{b}.$$

These values are often used later.

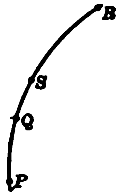
47. Cotangent and Tangent Relations.—If the angles between the poles of three faces in a zone are known, the angle between any one of them and the pole of a fourth face can be calculated by a formula called the *cotangent formula*. Conversely, if the angular position of this fourth face is given, the ratio of its indices can be calculated.

Let P, Q, S, R be the poles of four faces in a zone, taken in such an order* that PQ < PR, and let the indices of these faces be respectively:

$$\begin{array}{cccc} P & Q & R & S \\ hkl & pqr & uvw & xyz \end{array}$$

Then it may be proved that

68.



$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{(P.Q)}{(Q.R)} \cdot \frac{(S.R)}{(P.S)},$$

where

$$\frac{(P.Q)}{(Q.R)} = \frac{kr - lq}{qw - rv} = \frac{lp - hr}{ru - pw} = \frac{hq - kp}{pv - qu},$$

$$\frac{(S.R)}{(P\ S)} = \frac{wy - zv}{kz - ly} = \frac{zu - xw}{lx - hz} = \frac{xv - yu}{hy - kx}.$$

If one of these fractions reduces to an indeterminate form, $\frac{0}{0}$, then one of the others must be taken in its place.

This formula is chiefly used in the monoclinic and triclinic systems; and some special cases are referred to under these systems.

The cotangent relation becomes much simplified for a rectangular zone, that is, a zone between a pinacoid and a face in the zone of the other pinacoids at right angles to it. Thus if P*a*, P*b*, P*c*, Q*a*, Q*b*, Q*c* represent respectively the angles between two faces in the same rectangular zone, viz., P (*hkl*) and Q (*pqr*) and the pinacoids *a* (100), *b* (010), *c* (010), the following relations hold good:

$$\frac{h}{p} \cdot \frac{\tan Pa}{\tan Qa} = \frac{k}{q} = \frac{l}{r};$$

$$\frac{h}{p} = \frac{k}{q} \cdot \frac{\tan Pb}{\tan Qb} = \frac{l}{r};$$

$$\frac{h}{p} = \frac{k}{q} = \frac{l}{r} \cdot \frac{\tan Pc}{\tan Qc}.$$

---

[*] In the application of this principle it is essential that the planes should be taken in the proper order, as shown above; to accomplish this it is often necessary to use the indices and corresponding angles, not of (*hkl*), but the face opposite ($\bar{h}\bar{k}\bar{l}$), etc.

As a further simplification of the above equations for the case of prismatic planes hk and $pq0$, or domes $h0l$ and $p0r$ or $0kl$ and $0qr$, between two pinacoid planes, we have

$$\frac{\tan(100 \wedge hk0)}{\tan(100 \wedge pq0)} = \frac{k}{h} \cdot \frac{p}{q};$$

$$\frac{\tan(001 \wedge h0l)}{\tan(001 \wedge p0r)} = \frac{h}{l} \cdot \frac{r}{p};$$

$$\frac{\tan(001 \wedge 0kl)}{\tan(001 \wedge 0qr)} = \frac{k}{l} \cdot \frac{r}{q}.$$

These equations are the ones ordinarily employed to determine the symbol of any pri matic plane or dome.

The most common and important application of this tangent principle is where tl positions of the unit faces 110, 101, 011 are known, then the relation becomes

$$\frac{\tan(100 \wedge hk0)}{\tan(100 \wedge 110)} = \frac{k}{h}, \quad \text{or} \quad \frac{\tan(010 \wedge hk0)}{\tan(010 \wedge 110)} = \frac{h}{k}.$$

Also,

$$\frac{\tan(001 \wedge h0l)}{\tan(001 \wedge 101)} = \frac{h}{l}, \qquad \frac{\tan(001 \wedge 0kl)}{\tan(001 \wedge 011)} = \frac{k}{l}.$$

Thus the tangents of angles between the base, 001, and 102, 203, 302, 201, etc., a respectively $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{2}$, 2 times the tangent of the angle between 001 and 101. Again, tl tangent of the angle $100 \wedge 120$ is twice the tangent of $100 \wedge 110$ $\left(\text{here } \frac{k}{h} = 2\right)$, and on half the tangent of $010 \wedge 110$.

48. Formulas for Spherical Triangles.—For convenience, some of the more importa formulas for the solution of spherical triangles are here added.

In right-angled spherical triangles $C = 90°$.

$$\sin A = \frac{\sin a}{\sin h}, \qquad \sin B = \frac{\sin b}{\sin h},$$

$$\cos A = \frac{\tan b}{\tan h}, \qquad \cos B = \frac{\tan a}{\tan h},$$

$$\tan A = \frac{\tan a}{\sin b}, \qquad \tan B = \frac{\tan b}{\sin a},$$

$$\sin A = \frac{\cos B}{\cos b}, \qquad \sin B = \frac{\cos A}{\cos a},$$

$$\cos h = \cos a \cos b,$$

$$\cos h = \cot A \cot B.$$

In oblique-angled spherical triangles familiar relations are as follows:

(1) $\sin A : \sin B = \sin a : \sin b$;
(2) $\cos a = \cos b \cos c + \sin b \sin c \cos A$;
(3) $\cot b \sin c = \cos c \cos A + \sin A \cot B$;
(4) $\cos A = -\cos B \cos C + \sin B \sin C \cos a$.

In calculation it is often more convenient to use, instead of the latter formulas, thc especially arranged for logarithms, which will be found in any of the many books devot to mathematical formulas.

I. ISOMETRIC SYSTEM.

49. THE ISOMETRIC SYSTEM embraces all the forms which are referred to three equal axes at right angles to each other. Each of these axes is designated by the letter *a*.

There are five groups here included, of which the normal group,* possessing the highest degree of symmetry for the system and, indeed, for all crystals, is by far the most important. Two of the other groups, the pyritohedral and tetrahedral groups, also have numerous representatives among minerals.

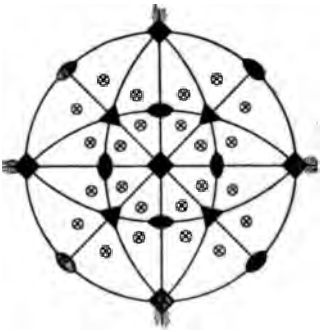
1. NORMAL GROUP (1). GALENA TYPE.

50. Symmetry.—Of each of the types of solids enumerated in the following table, as belonging to this group, as of all their combinations, it is true † that there are three like principal planes of symmetry, whose intersections fix the position of the crystallographic axes (see Fig. 12, p. 9). There are also six other auxiliary planes of symmetry ; these are situated diagonally to the others, each two equally inclined (45°) to the adjacent planes of chief symmetry, that is, to the axial planes.

Further, the crystals of this group have three principal axes of tetragonal symmetry, the cubic or crystallographic axes ; four axes of trigonal symmetry, the octahedral axes ; six axes of binary symmetry, the dodecahedral axes (see Art. **16**, also the following paragraph). These axes are shown in Figs. 17, 18, 19, p. 10.

The accompanying spherical projection (Fig. 69), constructed in accordance with the principles explained in Art. **42**, shows the distribution of the faces of the general form, *hkl*, and hence represents clearly the symmetry of the group. Compare also the projection given later, Fig. 110, p. 41.

69.



51. Forms.—The various possible forms belonging to this group, and possessing the symmetry defined, may be grouped under seven types of solids. These are enumerated in the following table, commencing with the most simple. The symbols are given in accordance with both the systems of Miller and Naumann; also the full expression showing the general position of the planes with relation to the axes. The last, however, are reduced to the form, corresponding to (2) in Art. **34**, which shows how the Naumann symbols are derived.

---

[*] It is called *normal*, as before stated, since it is the most common and hence by far the most important group under the system ; also, more fundamentally, because the forms here included possess the highest grade of symmetry possible in the system. There are five forms in this system, each geometrically a cube, but only that of this normal group actually has the full symmetry as regards molecular structure which its geometrical shape suggests. If a crystal is said to belong to the isometric system, without further qualification, it is to be understood that it is included here. Similar remarks apply to the normal groups of the other systems.

[†] The symmetry of the normal groups of the different systems has been already briefly explained in Art. **25**.

	Miller.		Naumann.
1. Cube	(100)	$a : \infty a : \infty a$	$\infty O \infty$ or $i\text{-}i$
2. Octahedron	(111)	$a : a : a$	O or 1
3. Dodecahedron	(110)	$a : a : \infty a$	∞O or i
4. Tetrahexahedron	($hk0$)	$a : na : \infty a$	∞On or $i\text{-}n$
as, (310) i-3; (210) i-2; (320) i-$\frac{3}{2}$, etc.			
5. Trisoctahedron	(hhl)	$a : a : ma$	mO or m
as, (331) 3; (221) 2; (332) $\frac{3}{2}$, etc.			
6. Trapezohedron	(hll)	$a : ma : ma$	mOm or $m\text{-}m$
as, (311) 3-3; (211) 2-2; (322) $\frac{3}{2}$-$\frac{3}{2}$, etc.			
7. Hexoctahedron	(hkl)	$a : na : ma$	mOn or $m\text{-}n$
as, (421) 4-2; (321) 3-$\frac{3}{2}$, etc.			

In the general expression of Miller's symbols, $h > k > l$. In those of Naumann, $m > 1$.

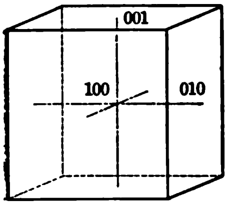
Attention is called to the letters uniformly used in this work and in Dana's System of Mineralogy (1892) to designate certain of the isometric forms.* They are:

Cube: *a*.
Octahedron: *o*.
Dodecahedron: *d*.
Tetrahexahedrons: $e = 210$, i-2; $f = 310$, i-3; $g = 320$, i-$\frac{3}{2}$; $h = 410$, i-4.
Trisoctahedrons: $p = 221$, 2; $q = 331$, 3; $r = 332$, $\frac{3}{2}$; $\rho = 441$, 4.
Trapezohedrons: $m = 311$, 3-3; $n = 211$, 2-2; $\beta = 322$, $\frac{3}{2}$-$\frac{3}{2}$.
Hexoctahedrons: $s = 321$, 3-$\frac{3}{2}$; $t = 421$, 4-2.

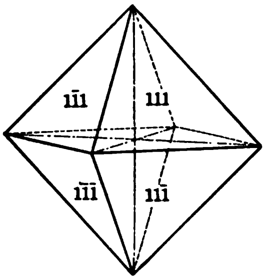
52. Cube.—The cube, whose general symbol is (100), is shown in Fig. 70. It is bounded by six similar faces, each parallel to two of the axes. Each face is a square, and the interfacial angles are all 90°. The faces of the cube are parallel to the principal or axial planes of symmetry. The lines joining the opposite solid angles of the cube are called the octahedral or trigonal interaxes; those joining the middle points of opposite edges are the dodecahedral interaxes (see Figs. 17, 18, p. 10).

53. Octahedron.—The octahedron, shown in Fig. 71, has the general symbol (111). It is bounded by eight similar faces, each meeting the three axes at equal distances. Each face is an equilateral triangle with plane angles of 60°. The normal interfacial angle, ($111 \wedge 1\bar{1}1$), is 70° 31′ 44″.

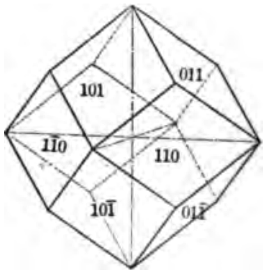
70.



71.



72.



54. Dodecahedron.—The rhombic dodecahedron, shown in Fig. 72, has the general symbol (110). It is bounded by twelve faces, each of which meets two of the axes at equal distances and is parallel to the third axis. Each face is a rhomb with plane angles of 60° and 120°. The real or interior interfacial angle is 120°, or the angle between two adjacent poles, that is, the normal interfacial angle, is 60°. The faces of the dodecahedron are parallel to the six auxiliary, or diagonal, planes of symmetry.

---

* The usage followed here (as also in the other systems) is in most cases that of Miller (1852).

It will be remembered that, while the forms described are designated respectively by the symbols (100), (111), and (110), each face of any one of the forms has its own symbol. Thus for the cube the six faces have the symbols

$$100,\quad 010,\quad 001,\quad \bar{1}00,\quad 0\bar{1}0,\quad 00\bar{1}.$$

For the octahedron the symbols of the eight faces are :

$$\begin{array}{lllll} \text{Above} & 111, & \bar{1}11, & \bar{1}\bar{1}1, & 111; \\ \text{Below} & 11\bar{1}, & \bar{1}1\bar{1}, & 11\bar{1}, & 1\bar{1}1. \end{array}$$

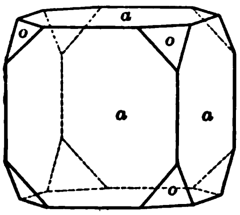
For the dodecahedron, the symbols of the twelve faces are :

$$\begin{array}{llll} 110, & \bar{1}10, & \bar{1}\bar{1}0, & 1\bar{1}0, \\ 101, & 101, & \bar{1}01, & 10\bar{1}, \\ 011, & 0\bar{1}1, & 011, & 01\bar{1}. \end{array}$$

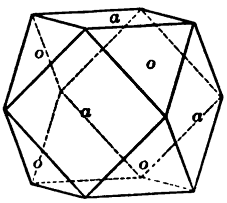
These should be carefully studied with reference to the figures (and to models), and also to the spherical projection (Fig. 110). The student should become thoroughly familiar with these individual symbols and the relations to the axes which they express, so that he can give at once the symbol of any face required.

55. Combinations of the Cube, Octahedron, and Dodecahedron.—Figs. 73, 74, 75 represent combinations of the cube and octahedron ; Figs. 76, 79, of the cube and dodecahedron ; Figs. 77, 78, of the octahedron and dodecahedron ; finally, Figs. 80, 81 show combinations of the three forms. The predominating form, as the cube in Fig. 73, the octahedron in Fig 75, etc., is usually said to be *modified* by the faces of the other forms. In Fig. 74 the cube and octahedron are said to be "in equilibrium," since the faces of the octahedron meet at the middle points of the edges of the cube.

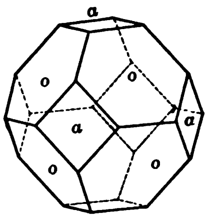
73.



74.



75.

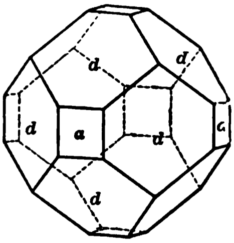


It should be carefully noticed, further, that the octahedral faces replace the solid angles of the cube, as regular triangles equally inclined to the adjacent cubic faces, as shown in Fig. 73. Again, the square cubic faces replace the six solid angles of the octahedron, being equally inclined to the adjacent octahedral faces (Fig. 75). The faces of the dodecahedron *truncate* * the twelve similar edges of the cube, as shown in Fig. 79. They also truncate the twel edges of the octahedron (Fig. 77). Further, in Fig. 76 the cubic faces repla the six tetrahedral solid angles of the dodecahedron, while the octahedral fac replace its eight trihedral solid angles (Fig. 78).

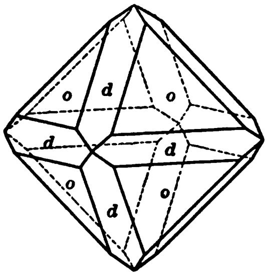
---

* The words *truncate*, *truncation*, are used only when the modifying face makes equal angles with the adjacent similar faces.

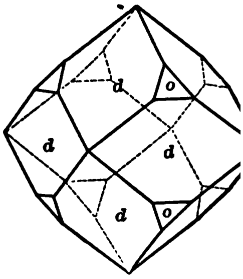
76.



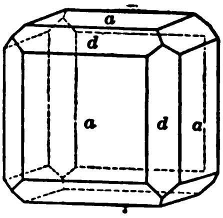
77.



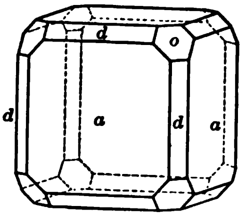
78.



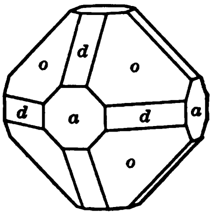
79.



80.



81.



The normal interfacial angles for adjacent faces are as follows :

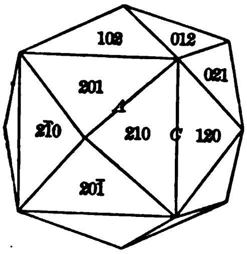
Cube on octahedron, *ao*, $100 \wedge 111 = 54° 44' 8''$.
Cube on dodecahedron, *ad*, $100 \wedge 110 = 45° 0' 0''$.
Octahedron on dodecahedron, *od*, $111 \wedge 110 = 35° 15' 52''$.

56. As explained in Art. **18**, actual crystals always deviate more or less wid from the ideal solids figured, in consequence of the unequal development of like fac Such crystals, therefore, do not satisfy the geometrical definition of right symmetry re tively to the three principal and the six auxiliary planes mentioned on p. 33, but they conform to the conditions of crystallographic symmetry, requiring like angular position similar faces. Again, it will be noted that in a combination form many of the faces do actually meet the axes within the crystal, as, for example, the octahedral face *o* in Fig. It is still true, however, that this face would meet the axes at equal distances if produc and since the *axial ratio* is the essential point in the case of each form, and the *act lengths* of the axes are of no importance, it is not necessary that the faces of the differ forms in a crystal should be referred to the same actual axial lengths. The above rema will be seen to apply also to all the other forms and combinations of forms described in pages following.

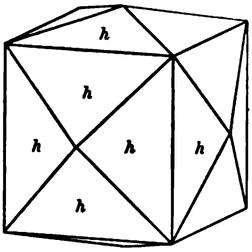
57. Tetrahexahedron.—The tetrahexahedron (Figs. 82, 83, 84) is bound by twenty-four faces, each of which is an isosceles triangle. Four of th faces together occupy the position of one face of the cube (hexahedron) wher the name commonly applied to this form. The general symbol is (*hk* hence each face is parallel to one of the axes while it meets the other two a at unequal distances. There are two kinds of edges, lettered *A* and *C* in F 82 ; the interfacial angle of either edge is sufficient to determine the syml of a given form (see below). The angles of some of the common forms given on a later page (p. 42).

There may be an indefinite number of tetrahexahedrons, as the ratio of the intercepts of the two axes, and hence of *h* to *k* varies; for example, (410), (310), (210), (320), etc. The form (210) is shown in Fig. 82; (410) in Fig. 83, and (530) in Fig. 84. All the tetrahexahedrons fall in a zone with a cubic face and a dodecahedral face. As *h* increases relatively to *k* the form approaches the cube (in which $h : k = \infty : 1$ or $1 : 0$), while as it diminishes and becomes more and more nearly equal to *k* in value it approaches toward the dodecahedron; for which $h = k$. Compare Fig. 83 and Fig. 84; also Fig. 110. The special symbols belonging to each face of the tetrahexahedron should be carefully noted.

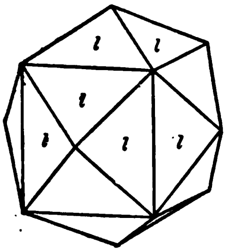
82.



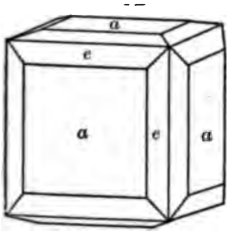
83.



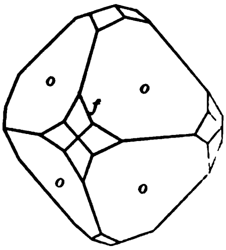
84.



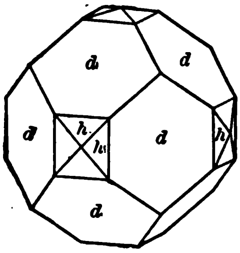
85.



86.



87.



The faces of the tetrahexahedron bevel* the twelve similar edges of the cube, as in Fig. 85; they replace the solid angles of the octahedron by four faces inclined on the edges (Fig. 86), and also the tetrahedral solid angles of the dodecahedron by four faces inclined on the faces (Fig. 87).

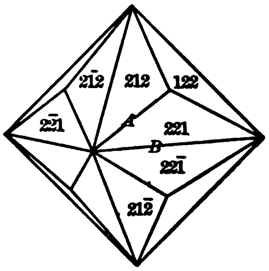
58. Trisoctahedron.—The trisoctahedron (Fig. 88), or, more definitely, the trigonal trisoctahedron, is bounded by twenty-four similar faces; each of these is an isosceles triangle, and three together occupy the position of an octahedral face, whence the common name. Further, to distinguish it from the trapezohedron or tetragonal trisoctahedron, it is sometimes called the trigonal trisoctahedron. There are two kinds of edges, lettered *A* and *B* in Fig. 88, and the interfacial angle corresponding to either is sufficient for the determination of the special symbol.

---

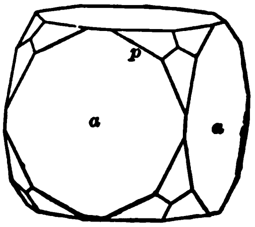
* The word *bevel* is used when two like faces replace the edge of a form and hence are inclined at equal angles to its adjacent similar faces.

The general symbol is (*hhl*); common forms are (221), (331), etc. E

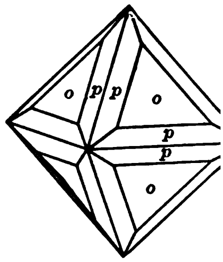
88.



89.



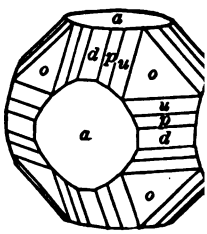
90.



Galena.

face of the trisoctahedron meets two of the axes at a distance less than un and the third at the unit length, or (which is an identical expression *) it meets two of the axes at the unit length and the third at a distance greater than unity. The symbols belonging to each face should be carefully noted. The normal interfacial angles for some of the more common forms are given on a later page.

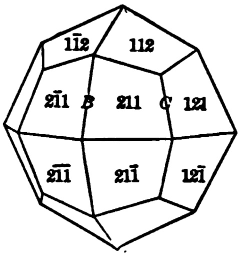
91.



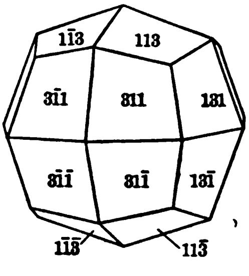
Galena.

59. Trapezohedron.—The trapezohedron † (Figs. 92, 93) is bounded by twenty-four similar faces, each of them a quadrilateral or trapezium. It also bears in appearance a certain relation to the octahedron, whence the name, sometimes employed, of tetragonal trisoctahedron. There are two kinds of edges, lettered *B* and *C*, in Fig. 92. The general symbol is *hll*; common forms are (311), (211), (322), etc. Of the fac each cuts an axis at a distance less than unity, and the other two at the u length, or (again, an identical expression) one of them intersects an axis at

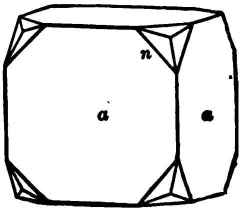
92.



93.



94.



Analcite.

unit length and the other two at distances greater than unity. The symb belonging to each face should be carefully noted. The normal interfac angles for some of the common forms are given on a later page. Another name for this form is icositetrahedron.

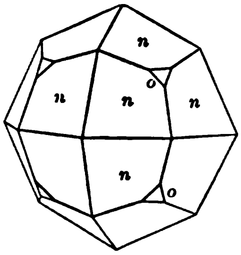
---

* Since $\frac{1}{2}a : \frac{1}{2}b : \frac{1}{1}c = 1a : 1b : 2c$. The student should read again carefully the expla tions in Art. **34**.

† It will be seen later that the name trapezohedron is also given to other solids wh faces are trapeziums, conspicuously to the tetragonal trapezohedron and the trigo trapezohedron.

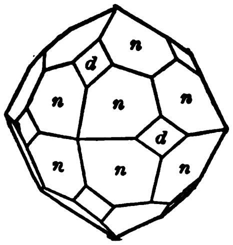
60. The combinations of these forms with the cube, octahedron, etc., should be carefully studied. It will be seen (Fig. 89) that the faces of the trisoctahedron replace the solid angles of the cube as three faces equally inclined on the *edges*. The faces of the trapezohedron appear as three equal triangles equally inclined to the cubic *faces* (Fig. 94).

95.



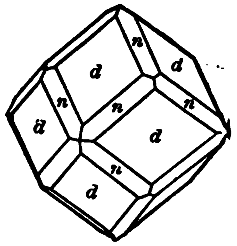
Analcite.

96.



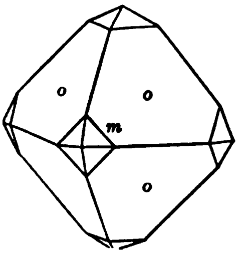
Garnet.

97.



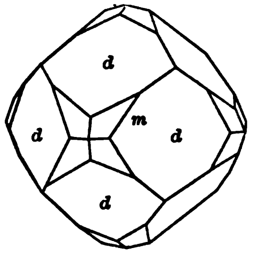
Garnet.

98.



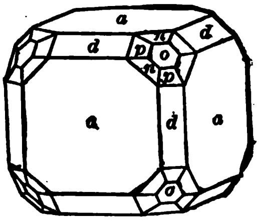
Spinel.

99.



Magnetite.

100.



Amalgam.

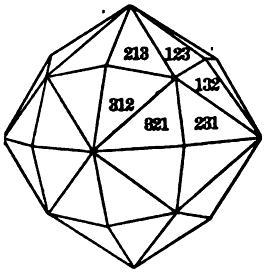
Again, the faces of the trisoctahedron bevel the edges of the octahedron (Fig. 90, also Fig. 91, with *p* (221) and *u* (554)), while those of the trapezohedron are triangles inclined to the faces at the extremities of the cubic axes (Fig. 98). Still again, the faces of the trapezohedron (211) truncate the edges of the dodecahedron (110), as shown in Fig. 97; this can be proved to follow at once from the zonal relations (Arts. 43, 44), cf. also Fig. 110. The position of the faces of the form (311), in combination with *o*, is shown in Fig. 98; with *d* in Fig. 99. Fig. 100 shows both the trisoctahedron *p* (221) and the trapezohedron *n* (211) with *a*, *o*, and *d*.

It should be added that the trapezohedron *n* (211) is a common form both alone and in combination; *m* (311) is common in combination. The trisoctahedron alone is rarely met with, though in combination (Figs. 90, 91, 100) it is not uncommon.

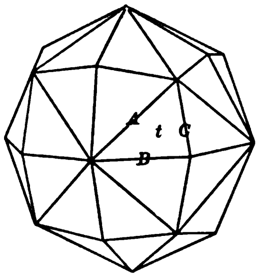
61. Hexoctahedron.—The hexoctahedron, Figs. 101, 102, is the general form in this system; it is bounded by forty-eight similar faces, each of which is a scalene triangle, and each intersects the three axes at unequal distances. The general symbol is (*hkl*); common forms are (321), shown in Fig. 101, and (421), in Fig. 102. The symbols of the individual faces, as shown in Fig. 101 and more fully in the projection (Fig. 110), should be carefully studied.

The hexoctahedron has three kinds of edges lettered *A*, *B*, *C* (longer, middle, shorter) in Fig. 102; the angles of two of these edges are needed to fix the symbol unless the zonal relations can be made use of. In Fig. 104 the faces of the hexoctahedron bevel the dodecahedral edges, and hence for this form $h = k + l$; the form *s* has the special symbol (321). The hexoctahedron alone is a very rare form, but it is seen in combination with the cube (Fig. 103, fluorite) as six small faces replacing each solid angle. Fig. 104 is common with garnet; Fig. 105 shows a combination observed in native copper ($y = 18 \cdot 10 \cdot 5$), and Fig. 106 with native gold ($x = 18 \cdot 10 \cdot 1$). The angles of some common hexoctahedrons are given on p. 42.

101.

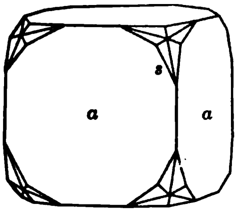


102.



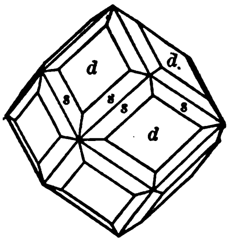
$t = (421)$.

103.



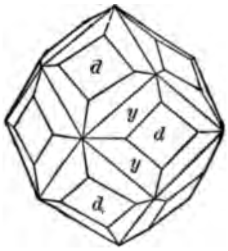
Fluorite.

104.



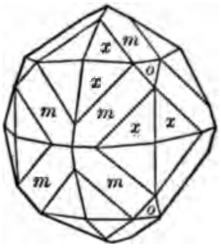
Garnet.

105.



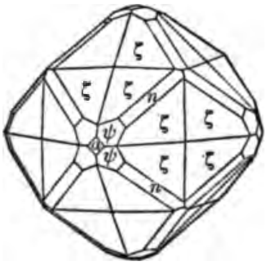
Copper.

106.



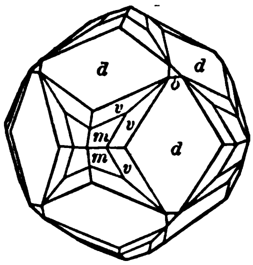
Gold.

107.



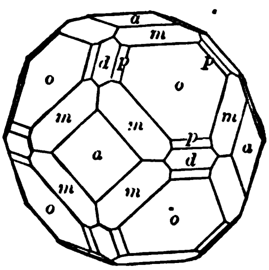
Garnet.

108.



Magnetite.

109.



Microlite.

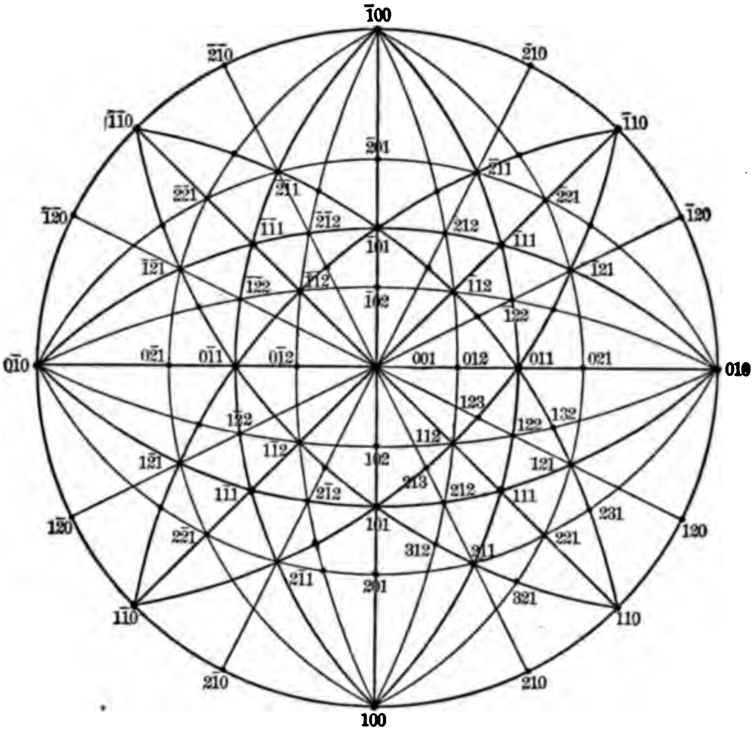
62. Some further examples of isometric forms are given in Figs. 107, 108, 109. In Fig. 107, ψ is the trapezohedron (722); ζ is the hexoctahedron

(64 · 63 · 1), this last being called a *vicinal form*, since it deviates but slightly in angular position from the simple form ordinarily occurring (*d*, 110); hence the complex indices. In Fig. 108, *v* is the hexoctahedron (531). In Fig. 109, $m = (311)$, $p = (221)$, etc.

63. Pseudo-symmetry in the Isometric System.—Isometric forms, by development in the direction of one of the cubic axes, simulate tetragonal forms. More commonly, and of greater interest, are forms simulating those of rhombohedral symmetry by extension, or flattening, in the direction of an octahedral axis. Both these cases are illustrated later. Conversely, certain rhombohedral forms resemble an isometric octahedron in angle and complex twinning.

64. Spherical Projection.—The spherical projection, Fig. 110, shows the positions of the poles of the faces of the cube (100), octahedron (111), and dodecahedron (110); also the tetrahexahedron (210), the trisoctahedron (221), the trapezohedron (211), and the hexoctahedron (321).

110.



The student should study this projection carefully, noting the symmetry marked by the zone-circles 100, 001, 1̄00, and 100, 010, 1̄00; also by 110, 001, 1̄1̄0; 1̄10, 001, 11̄0; 010, 101, 01̄0; 010, 1̄01, 01̄0. Note further that the faces of a given form are symmetrically distributed about a cubic face, as 001; a dodecahedral face, as 101; an octahedral face, as 111.

Note further the symbols that belong to the individual faces of each form, comparing the projection with the figures which precede.

Finally, note the prominent *zones of planes;* for example, the zone between two cubic faces including a dodecahedral face and the faces of all possible tetrahexahedrons. Again, the zones from a cubic face (as 001) through an octahedral face (as 111) passing through the trisoctahedrons, as 113, 112, 223, and the trapezohedrons 332, 221, 331, etc. Also the zone from one dodecahedral face, as 110, to another, as 101, passing through 321, 211, 312, etc. At the same time compare these zones with the same zones shown on the figures already described.

65. Angles of Common Isometric Forms.*

TETRAHEXAHEDRONS.

	Edge A	Edge C	Angle on	Angle on
Cf. Fig. 82.	210 ∧ 201, etc.	210 ∧ 120, etc.	*a* (100, *i-i*)	*o* (111, 1)
410, *i*-4	19 45	61 55¾	14 2¼	45 33¾
310, *i*-3	25 50½	53 17¾	18 26	43 5¼
520, *i*-$\frac{5}{2}$	30 27	46 23¾	21 48	41 22
210, *i*-2	36 52¼	36 52¼	26 34	39 14
530, *i*-$\frac{5}{3}$	42 40	28 4¼	30 57¾	37 37
320, *i*-$\frac{3}{2}$	46 11¼	22 37¼	33 41½	36 48½
430, *i*-$\frac{4}{3}$	50 12½	16 15½	36 52¼	36 4¼
540, *i*-$\frac{5}{4}$	52 25¾	12 40¾	38 39½	35 45½

TRISOCTAHEDRONS.

	Edge A	Edge B	Angle on	Angle on
Cf. Fig. 88.	221 ∧ 212, etc.	221 ∧ 22$\bar{1}$, etc.	*a* (100, *i-i*)	*o* (111, 1)
332, $\frac{3}{2}$	17 20½	50 28¾	50 14¼	10 1½
221, 2	27 16	38 56½	48 11	15 47½
552, $\frac{5}{2}$	33 33½	31 35¼	47 7½	19 28¼
331, 3	37 51¾	26 31½	46 30½	22 0
772, $\frac{7}{2}$	40 59	22 50½	46 7½	23 50½
441, 4	43 20½	20 2¾	45 52	25 14½

TRAPEZOHEDRONS.

	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 92.	211 ∧ 2$\bar{1}$1, etc.	211 ∧ 121, etc.	*a* (100, *i-i*)	*o* (111, 1)
411, 4-4	27 16	60 0	19 28¼	35 15¾
722, $\frac{7}{2}$-$\frac{7}{2}$	30 43¼	55 50¾	22 0	32 44
311, 3-3	35 5¾	50 28¾	25 14¼	29 29¾
522, $\frac{5}{2}$-$\frac{5}{2}$	40 45	43 20½	29 29¾	25 14¼
211, 2-2	48 11½	33 33½	35 15¾	19 28¼
322, $\frac{3}{2}$-$\frac{3}{2}$	58 2	19 45	43 18¾	11 25¼

HEXOCTAHEDRONS.

	Edge A	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 102.	321 ∧ 312, etc.	321 ∧ 32$\bar{1}$, etc.	321 ∧ 231, etc.	*a* (100, *i-i*)	*o* (111, 1)
421, 4-2	17 45¼	25 12½	35 57	29 12¼	28 6½
18·10·5, $\frac{18}{5}$-$\frac{9}{5}$	19 12½	27 17¾	30 58	31 50¾	25 57¼
18·10·1, 18-$\frac{9}{5}$	35 57¾	5 33¾	31 51¼	29 10½	35 41½
531, 5-$\frac{5}{3}$	27 39½	19 27¾	27 39½	32 18¾	28 33¾
321, 3-$\frac{3}{2}$	21 47¼	31 0¼	21 47¼	36 42	22 12½
432, 2-$\frac{4}{3}$	15 5½	43 36¼	15 5½	42 1¾	15 13½
431, 4-$\frac{4}{3}$	32 12¼	22 37¼	15 56½	38 19¾	25 4

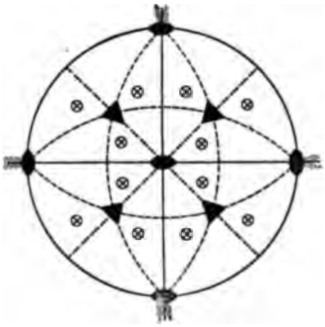
---

* A fuller list is given in the Introduction to Dana's System of Mineralogy, pp. xx–xxiii.

2. PYRITOHEDRAL GROUP (2). PYRITE TYPE.

66. Typical Forms and Symmetry.—The typical forms of the pyritohedral group are the *pyritohedron*, or pentagonal dodecahedron, Figs. 112, 113, and the *diploid*, or dyakis-dodecahedron, Fig. 118. The symmetry of these forms, as of the group as a whole, is as follows: There are but three planes of symmetry; these are parallel to the cubic faces and coincide with the planes of the cubic axes. The three crystallographic axes are axes of binary symmetry only; there are also four axes of trigonal symmetry coinciding with the octahedral axes.

111.

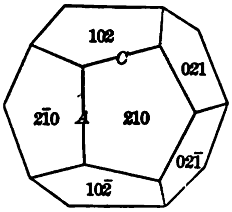


The spherical projection in Fig. 111 shows the distribution of the faces of the general form (*hkl*) and thus exhibits the symmetry of the group. This should be carefully compared with the corresponding projection (Fig. 69) for the normal group, so that the lower grade of symmetry here present be thoroughly understood. In studying the forms described and illustrated in the following pages, this matter of symmetry, especially in relation to that of the normal group, should be continually before the mind.

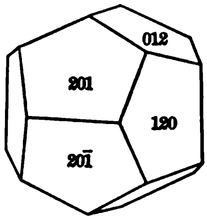
It will be observed that the faces of both the pyritohedron (Fig. 112) and the diploid (Fig. 118) are arranged in parallel pairs, and on this account these forms have been sometimes called *parallel hemihedrons*. Further, those authors who prefer to describe these forms as cases of hemihedrism call this type parallel-faced hemihedrism or pentagonal hemihedrism.

67. Pyritohedron.—The pyritohedron (Fig. 112) is so named because it is a typical form with the common species, pyrite. It is a solid bounded by twelve faces, each of which is a pentagon, but with one edge (*A*, Fig. 112) longer than the other four similar edges (*C*). It is often called a pentagonal dodecahedron, and indeed it resembles closely the regular dodecahedron of geometry, in which the faces are regular pentagons. This latter form is, however, as already noted (Art. 35), an impossible form in crystallography.

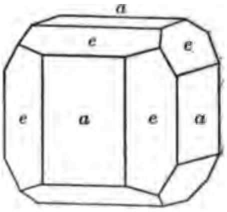
112.



113.



114.

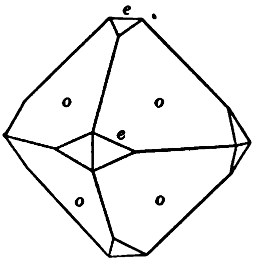


The general symbol is (*hk*0) or like that of the tetrahexahedron of the normal group. Hence each face is parallel to one of the axes and meets the other two axes at unequal distances. Common forms are (410), (310), (210), (320), etc. Besides the *plus* pyritohedron, as (210), there is also the complementary *minus* form* shown in Fig. 113; the symbol is here (120). Other common forms are (250), (230), (130), etc.

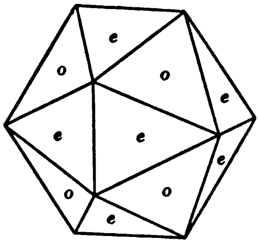
The plus and minus pyritohedrons together embrace twenty-four faces, having the same position as the twenty-four like faces of the tetrahexahedron of the normal group.

68. Combinations.—The faces of the pyritohedron replace the edges of the cube, but make unequal angles with two adjacent cubic faces; on the other hand, when the pyritohedron is modified by the cube, its faces truncate the longer edges of the pentagons. Cf. Fig. 114.

115.



116.



117.

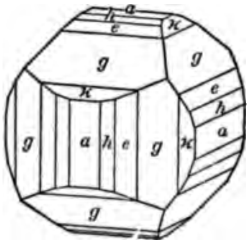
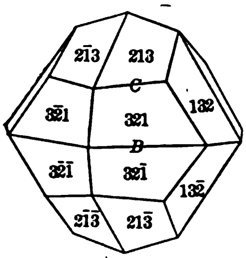


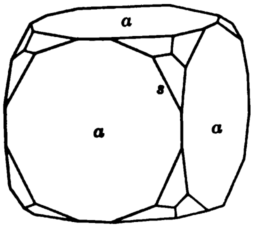
Fig. 115 shows the combination of the pyritohedron and octahedron, and in Fig. 116 these two forms are equally developed. The resulting combination bears a close similarity to the icosahedron, or regular twenty-faced solid, of geometry (see Art. 35). Here, however, of the twenty faces, the eight octahedral are equilateral triangles, the twelve others belonging to the pyritohedron are isosceles triangles. Fig. 117 shows a number of pyritohedrons with the cube (*a*), namely, *h* (410), *e* (210), *g* (320), and the minus form *κ* (450).

69. Diploid.—The diploid is bounded by twenty-four similar faces, each meeting the axes at unequal distances; its general symbol is hence (*hkl*), and common forms are (321), (421), etc. The form (321) is shown in Fig. 118; the symbols of its faces, as given, should be carefully studied. As seen in the figure, the faces are quadrilaterals or trapeziums; moreover, they are grouped in pairs, hence the common name diploid. It is also called a dyakisdodecahedron.

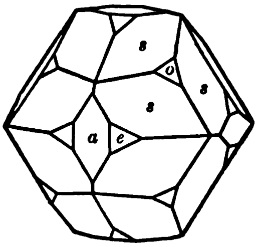
118.



119.



120.

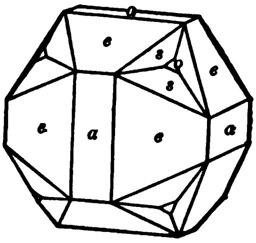


---

* The minus forms in this and similar cases have sometimes distinct letters, sometimes the same as the plus form, but distinguished by a subscript accent, as *e* (210) and *e*, (120).

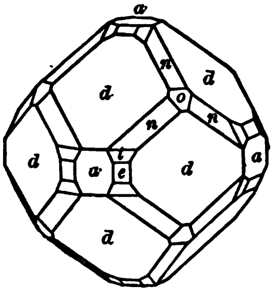
The complementary minus form bears to Fig. 118 the same relation as the minus to the plus pyritohedron. Its faces have the symbols 312, 231, 123, in the front octant, and similarly with the proper negative signs in the others. The plus and minus forms together obviously embrace all the faces of the hexoctahedron of the normal group.

121.



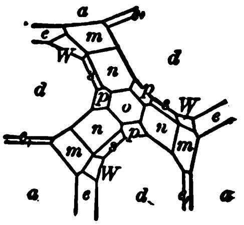
Pyrite.

122.



Pyrite.

123.

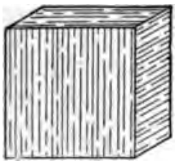


Pyrite.

In Fig. 119 the plus diploid is shown in combination with the cube. Here the three faces replace each of its solid angles. This combination form resembles that of Fig. 89, but the three faces are here unequally inclined upon two adjacent cubic faces. Other combinations of the diploid with the cube, octahedron, and pyritohedron are given in Figs. 120 and 121.

70. Other Forms.—If the pyritohedral type of symmetry be applied to planes each parallel to two of the axes, it is seen that this symmetry calls for six of these, and the resulting form is obviously a cube. This cube cannot be distinguished geometrically from the cube of the normal group, but it has its own characteristic molecular symmetry. Corresponding to this it is common to find cubes of pyrite with fine lines (striations) parallel to the alternate edges, as indicated in Fig. 124. These are due to the partial development of pyritohedral faces (210). On a normal cube such striations, if present, must be parallel to both sets of edges on each cubic face.

124.



Similarly to the cube, the remaining forms of this pyritohedral group, namely, (111), (110), (*hhl*), (*hll*), have the same geometrical form, respectively, as the octahedron, dodecahedron, the trisoctahedrons and trapezohedrons of the normal group. In molecular structure, however, these forms are distinct, each having the symmetry described in Art. **66**.

71. Other combinations of pyritohedral forms are shown in Figs. 122, 123, both of the species pyrite. Fig. 122 is dodecahedral in habit, with the diploid *t* (421), the trapezohedron *n* (211), also *a* (100), *o* (111), *e* (210). In Fig. 123, a single angle of a pyrite crystal is represented with *a* (100), *o* (111), *d* (110); the two pyritohedrons *e* (210) and *e*, (120); the trisoctahedron *p* (221); the trapezohedrons *n* (211), *m* (311); the diploids *s* (321), *W* (851).

This species illustrates well the complexity that may be observed among the crystals of a given mineral. Not only is there wide variation in habit, but the occurring forms are also very numerous. Thus some thirty-five pyritohedrons (+ and —) have been noted and a like number of diploids; also five trisoctahedrons and eleven trapezohedrons.

72. Angles.—The following tables contain the angles of some common forms:

PYRITOHEDRONS.

Cf. Fig. 112.	Edge A $210 \wedge 2\bar{1}0$, etc.	Edge C $210 \wedge 102$, etc.	Angle on *a* (100, *i-i*)	Angle on *o* (111, 1)
410	28° 4¼′	76° 23⅓′	14° 2¼′	45° 33¾′
310	36 52¼	72 32⅓	18 26	43 5¼
520	43 36¼	69 49¾	21 48	41 22
210	53 7¾	66 25¼	26 34	39 14
530	61 55¾	63 49¼	30 57¾	37 37
320	67 22¾	62 30¾	33 41½	36 48⅓
430	73 44⅓	61 19	36 52¼	36 4¼
540	77 19¼	60 48¼	38 39⅓	35 45⅓
650	79 36¾	60 32⅓	39 48¼	35 35¾

DIPLOIDS.

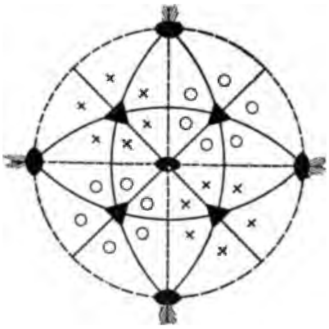
Cf. Fig. 118.	Edge A $321 \wedge 3\bar{2}1$, etc.	Edge B $321 \wedge 32\bar{1}$, etc.	Edge C. $321 \wedge 213$, etc.	Angle on *a* (100, *i i*)	Angle on *o* (111, 1)
421	51° 45¼′	25° 12⅓′	48° 11⅓′	29° 12¼′	28° 6⅓′
532	58 14⅓	37 51¾	35 20	35 47¾	20 30¾
531	60 56⅓	19 27¾	19 27¾	32 18¾	28 33¾
851	63 36¾	12 6	53 55¼	32 30¾	31 34
821	64 37½	31 0¼	38 12¼	36 42	22 12⅓
432	67 42⅓	43 36¼	26 17⅓	42 1¾	15 13⅓
431	72 4¾	22 37¼	43 3	38 19¾	25 4

3. TETRAHEDRAL GROUP (3). TETRAHEDRITE TYPE.

73. Typical Forms and Symmetry.—The typical form of this group, and that from which it derives its name, is the *tetrahedron*, shown in Figs. 126, 127. There are also three other distinct forms, shown in Figs. 133, 134, 135.

The symmetry of these forms is that which is characteristic of the entire group. There are six planes of symmetry, parallel respectively to the faces of a rhombic dodecahedron, but no planes of symmetry parallel to the cubic faces. The three cubic axes are axes of binary symmetry only, and the four octahedral axes are axes of trigonal symmetry. There is no center of symmetry.

125.



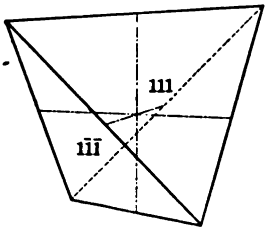
The spherical projection (Fig. 125) shows the distribution of the faces of the general form (*hkl*) and thus exhibits the symmetry of the group. It will be seen at once that the like faces are *all grouped in the alternate octants*, and this will be seen to be characteristic of all the forms peculiar to this group. The relation between the symmetry here described and that of the normal group must be carefully studied.

In distinction from the pyritohedral forms whose faces were in parallel pairs, the faces of the tetrahedron and the analogous solids are inclined to each other, and hence they are sometimes spoken of as *inclined hemihedrons*, and the type of so-called hemihedrism here illustrated is then called inclined or tetrahedral hemihedrism.

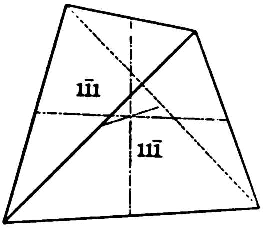
74. Tetrahedron.—The tetrahedron,* as its name indicates, is a four-faced solid, bounded by planes meeting the axes at equal distances. Its general symbol is (111), and the four faces of the plus form (Fig. 126) have the symbols 111, $\bar{1}\bar{1}1$, $\bar{1}1\bar{1}$, $1\bar{1}\bar{1}$. These are four of the faces of the octahedron of the normal group (Fig. 71), and those four which belong to the alternate octants as required by the symmetry already defined.

Each of the four faces of the tetrahedron is an equilateral triangle; the (normal) interfacial angle is 109° 29′ 16″. The tetrahedron is the regular triangular pyramid of geometry, but crystallographically it must be so placed that the axes join the middle points of opposite edges, and one axis is vertical.

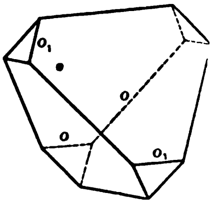
126.



127.

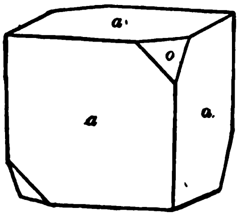


128.

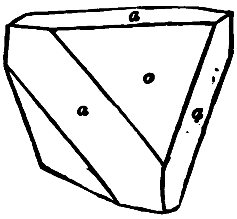


There are two possible tetrahedrons: the *plus* tetrahedron (111), designated by the letter *o*, which has already been described, and the *minus* tetrahedron, having the same geometrical form and symmetry, but the symbols of its four faces are $\bar{1}11$, $1\bar{1}1$, $11\bar{1}$, $\bar{1}\bar{1}\bar{1}$. This second form is shown in Fig. 127; it is usually designated by the letter $o_{,}$. These two forms are, as stated above, identical in geometrical shape, but they may be distinguished in many cases by the tests which serve to reveal the molecular structure, particularly the etching-figures. It is probable that the plus and minus tetrahedrons of sphalerite (see that species) have a constant difference in this particular, which makes it possible to distinguish them on crystals from different localities and of different habit.

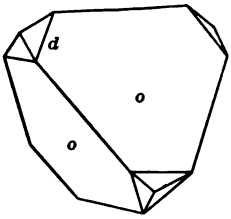
129.



130.



131.



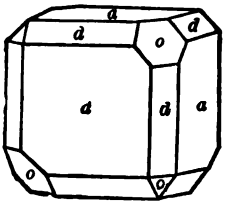
If both tetrahedrons are present together, the form in Fig. 128 results. This is geometrically an octahedron when they are equally developed, but crystallographically it is always only a combination of two unlike forms, the plus and minus tetrahedrons, which can be distinguished as already noted.

---

* This is one of the five regular solids of geometry, which include also the cube, octahedron, the regular pentagonal dodecahedron, and the icosahedron; the last two are impossible forms among crystals.

The tetrahedron in combination with the cube replaces the alternate solid angles as in Fig. 129. The cube modifying the tetrahedron truncates its edges as shown in Fig. 130. The normal angle between adjacent cubic and tetrahedral faces is 54° 44′. In Fig. 131 the dodecahedron is shown modifying the plus tetrahedron, while in Fig. 132 the cube is the predominating form with the plus and minus tetrahedrons and dodecahedron.

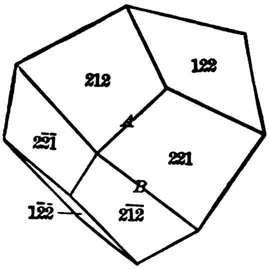
132.



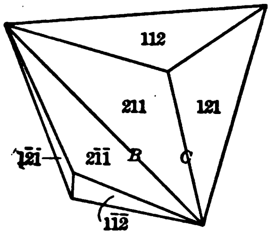
Boracite.

75. Other Typical Forms.—There are three other distinct types of solids in this group, having the general symbols (*hhl*), (*hll*), and (*hkl*). The first of these is shown in Fig. 133, here the symbol is (221). There are twelve faces, each a quadrilateral, belonging to this form, distributed as determined by the tetrahedral type of symmetry. They correspond to twelve of the faces of the trisoctahedron, namely, all those falling in alternate octants. This type of solid is sometimes called a *tetragonal tristetrahedron,* or a deltoid dodecahedron. It does not occur alone among crystals, but its faces are observed modifying other forms.

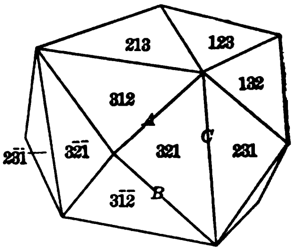
133.



134.



135.



There is also a complementary minus form, corresponding to the plus form, related to it in precisely the same way as the minus to the plus tetrahedron. Its twelve faces are those of the trisoctahedron which belong to the other set of alternate octants.

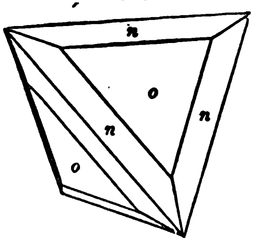
Another form, shown in Fig. 134, has the general symbol (*hll*), here (211); it is bounded by twelve like triangular faces, distributed after the type demanded by tetrahedral symmetry, and corresponding consequently to the faces of the alternate octants of the form (*hll*)—the trapezohedron—of the normal group. This type of solid is sometimes called a *trigonal tristetrahedron* or trigondodecahedon.* It is observed both alone and in combination; it is much more common than the form (*hhl*). There is here again a complementary minus form. Fig. 136 shows the plus form *n* (211) with the plus tetrahedron, and Fig. 137, the form *m* (311) with *a* (100), *o* (111), and *d* (110). In Fig. 138, the minus form *n,* ($2\bar{1}1$) is present.

---

* It is to be noted that the tetragonal tristetrahedron has faces which resemble those of the trapezohedron (tetragonal trisoctahedron), although it is related not to this but to the trisoctahedron (trigonal trisoctahedron). On the other hand, the faces of the trigonal tristetrahedron resemble those of the trisoctahedron, though in fact related to the trapezohedron.

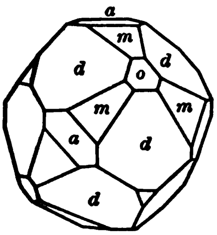
The fourth independent type of solids in this group is shown in Fig. 135. It has the general symbol (*hkl*), here (321), and is bounded by twenty-four faces distributed according to tetrahedral symmetry, that is, embracing all the faces of the alternate octants of the forty-eight-faced hexoctahedron. This form is sometimes called a *hexakistetrahedron*. The complementary minus form ($h\bar{k}l$) embraces the remaining faces of the hexoctahedron. The plus hexakistetrahedron, *v* (531), is shown in Fig. 138 with the cube, octahedron, and dodecahedron, also the minus trigonal tristetrahedron *n* ($2\bar{1}1$).

136.



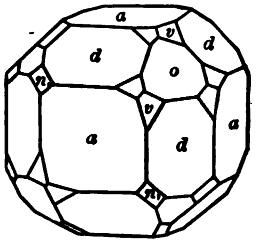
Tetrahedrite.

137.



Sphalerite.

138.



Boracite.

76. If the tetrahedral symmetry be applied in the case of planes each parallel to the two axes, it will be seen that there must be six such faces. They form a *cube* similar in geometrical appearance to the cube both of the normal and pyritohedral groups, but differing in its molecular structure, as can be readily proved, for example, by pyro-electricity. Similarly in the case of the planes having the symbol (110), there must be twelve faces forming a rhombic dodecahedron bearing the same relation to the like geometrical form of the normal group. The same is true again of the planes having the position expressed by the general symbol (*hk*0); there must be twenty-four of them and they together form a tetrahexahedron.

In this group, therefore, there are also seven types of forms, but only four of them are geometrically distinct from the corresponding forms of the normal group.

77. Angles.—The following tables contain the angles of some common forms:

TETRAGONAL TRISTETRAHEDRONS.

	Edge A	Edge B	Angle on	Angle on
Cf. Fig. 133.	221 ∧ 212, etc.	221 ∧ $2\bar{1}\bar{2}$, etc.	*a* (100, *i-i*)	*o* (111, 1)
332	17° 20½′	97° 50¼′	50° 14¼′	10° 1½′
221	27 16	90 0	48 11½	15 47½
552	33 33½	84 41	47 7¼	19 28¼
331	37 51¾	80 55	46 30½	22 0

TRIGONAL TRISTETRAHEDRONS.

	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 134.	211 ∧ $2\bar{1}\bar{1}$, etc.	211 ∧ 121, etc.	*a* (100, *i-i*)	*o* (111, 1)
411	38° 56½′	60° 0′	19° 28¼′	35° 15¾′
722	44 0¼	55 50¾	22 0	32 44
311	50 28¾	50 28¾	25 14½	29 29¾
522	58 59½	43 20½	29 29¾	25 14½
211	70 31¾	33 33½	35 15¾	19 28¼
322	86 37¾	19 45	43 18¾	11 25¼

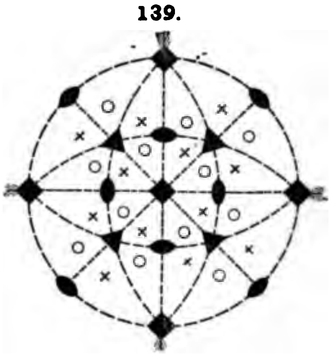
HEXAKISTETRAHEDRONS.

	Edge A	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 135.	321 ∧ 312, etc.	321 ∧ 31̄2̄, etc.	321 ∧ 231, etc.	*a* (100, *i-i*)	*o* (111, 1)
531	27° 39⅜′	57° 7⅛′	27° 39⅜′	32° 18⅝′	28° 33⅝′
321	21 47¼	69 4⅛	21 47¼	36 42	22 12⅛
432	15 5⅛	82 4⅛	15 5⅛	42 1¾	15 13⅛
431	32 12¼	67 22¾	15 56⅛	38 19¾	25 4

4. PLAGIHEDRAL GROUP (4). CUPRITE TYPE.

78. Typical Forms and Symmetry.—The fourth group under the isometric system is called the plagihedral or gyroidal group because the faces of the general form (*hkl*) are arranged in spiral order. This is shown on the spherical projection, Fig. 139, and also in Figs. 140, 141, which represent the single typical form of the group. These two complementary solids together embrace all the faces of the hexoctahedron. They are distinguished from one another by being called respectively right-handed and left-handed pentagonal icositetrahedrons. The other forms of the group are geometrically like those of the normal group.

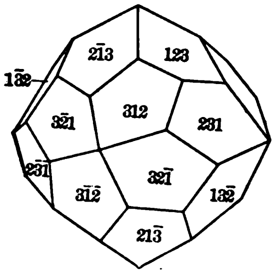
139.



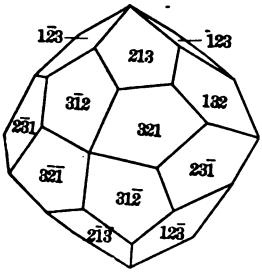
The symmetry characteristic of the group in general is as follows :

There are no planes of symmetry and no center of symmetry. There are, however, three axes of quaternary symmetry normal to the cubic faces, four axes of trigonal symmetry normal to the octahedral faces, and six axes of binary symmetry normal to the faces of the dodecahedron. In other words, it has all the axes of symmetry of the normal group while without planes or center of symmetry.

140.



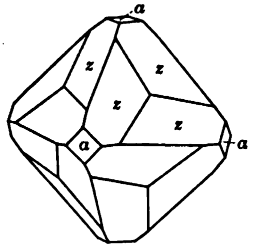
141.



79. It is to be noted that the two forms shown in Figs. 140, 141 are alike geometrically, but are not superposable; in other words, they are related to one another as is a right- to a left-hand glove. They are hence said to be *enantiomorphous*, and, as explained elsewhere, the crystals belonging here may be expected to show circular light polarization. It will be seen that the complementary plus and minus forms of the preceding groups, unlike those here, may be superposed by being rotated 90° about one of the crystallographic axes. This distinction between plus and minus forms, and between right- and left-handed enantiomorphous forms, exists also in the case of the groups of several of the other systems.

This group is rare among minerals ; it is represented by cuprite, sal ammoniac, sylvite, and halite. It is usually shown by the distribution of the small modifying faces, or by the form of the etching-figures. Fig. 142 shows a crystal of cuprite from Cornwall (Pratt) with the form *z* (13·10·12).

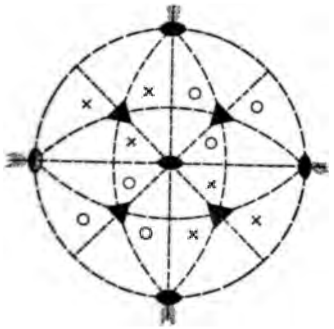
142.



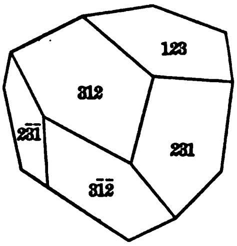
5. TETARTOHEDRAL GROUP (5). ULLMANNITE TYPE.

80. Symmetry and Typical Forms.—The fifth remaining possible group under the isometric system is illustrated by Fig. 144, which represents the twelve-faced solid corresponding to the general symbol (*hkl*). The distribution of its faces is shown in the projection, Fig. 143. This form is sometimes called a tetrahedral-pentagonal dodecahedron. It is seen to have one-fourth as many faces as the form (*hkl*) in the normal group, hence there are four similar solids which together embrace all the faces of the hexoctahedron. These four solids, which are distinguished as right-handed (+ and −) and left-handed (+ and −), are enantiomorphous, like those of Figs. 140 and 141, and hence the salts crystallizing here may be expected to also show circular polarization. The remaining forms of the group are (besides the cube and rhombic dodecahedron) the tetrahedrons, the pyritohedrons, the tetragonal and trigonal tristetrahedrons; geometrically they are like the solids of the same names already described. This group has no plane of symmetry and no center of symmetry. There are three axes of binary symmetry normal to the cubic faces, and four axes of trigonal symmetry normal to the faces of the tetrahedron.

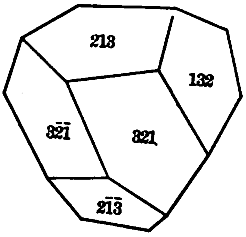
143.



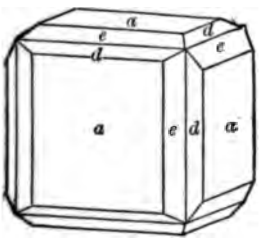
144.



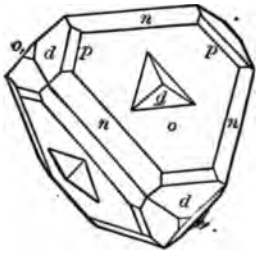
145.



146.



147.



This group is illustrated by artificial crystals of barium nitrate, strontium nitrate, sodium chlorate, etc. Further, the species ullmannite, which shows sometimes pyritohedral (Fig. 146) and again tetrahedral forms (Fig. 147), both having the same composition, must be regarded as belonging here.

Mathematical Relations of the Isometric System.

81. Most of the problems arising in the isometric system can be solved at once by the right-angled triangles in the sphere of projection (Fig. 110, p. 41) without the use of any formulas.

It will be remembered that the angles between a cubic face, as 100, and the adjacent face of a tetrahexahedron, 310, 210, 320, etc., can be obtained at once, since the tangent of this angle is equal to $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, or in general $\frac{k}{h}$.

$$\tan (hk0 \wedge 100) = \frac{k}{h}.$$

Since all the forms of a given symbol under different species have the same angles, the tables of angles already given are very useful.

These and similar angles may be calculated immediately from the sphere, or often more simply by the formulas given in the following article.

82. Formulas.—(1) The distance of the pole of any face P(*hkl*) from the cubic faces is given by the following equations. Here P*a* is the distance between (*hkl*) and (100); P*b* is the distance between (*hkl*) and (010); and P*c* that between (*hkl*) and (001).

These equations admit of much simplification in the various special cases, for (*hk*0), (*hhl*), etc.:

$$\cos^2 \mathrm{P}a = \frac{h^2}{h^2 + k^2 + l^2}; \qquad \cos^2 \mathrm{P}b = \frac{k^2}{h^2 + k^2 + l^2}; \qquad \cos^2 \mathrm{P}c = \frac{l^2}{h^2 + k^2 + l^2}.$$

(2) The distance between the poles of any two faces P(*hkl*) and Q(*pqr*) is given by the following equation, which in special cases may also be more or less simplified:

$$\cos \mathrm{PQ} = \frac{hp + kq + lr}{\sqrt{(h^2 + k^2 + l^2)(p^2 + q^2 + r^2)}}$$

(3) The calculation of the supplement interfacial or normal angles for the several forms may be accomplished as follows:

Trisoctahedron.—The angles A and B are, as before, the supplements of the interfacial angles of the edges lettered as in Fig. 88.

$$\cos \mathrm{A} = \frac{h^2 + 2hl}{2h^2 + l^2}; \qquad \cos \mathrm{B} = \frac{2h^2 - l^2}{2h^2 + l^2}.$$

For the *tetragonal-tristetrahedron* (Fig. 133), $\cos \mathrm{B} = \frac{h^2 - 2hl}{2h^2 + l^2}$.

Trapezohedron (Fig. 92). B and C are the supplement angles of the edges as lettered in the figure.

$$\cos \mathrm{B} = \frac{h^2}{h^2 + 2l^2}; \qquad \cos \mathrm{C} = \frac{2hl + l^2}{h^2 + 2l^2}.$$

For the *trigonal-tristetrahedron* (Fig. 134), $\cos \mathrm{B} = \frac{h^2 - 2l^2}{h^2 + 2l^2}$.

Tetrahexahedron (Fig. 82).

$$\cos \mathrm{A} = \frac{h^2}{h^2 + k^2}; \qquad \cos \mathrm{C} = \frac{2hk}{h^2 + k^2}.$$

For the *pyritohedron* (Fig. 112), $\cos \mathrm{A} = \frac{h^2 - k^2}{h^2 + k^2}$; $\qquad \cos \mathrm{C} = \frac{hk}{h^2 + k^2}$.

Hexoctahedron (Fig. 102).

$$\cos \mathrm{A} = \frac{h^2 + 2kl}{h^2 + k^2 + l^2}; \qquad \cos \mathrm{B} = \frac{h^2 + k^2 - l^2}{h^2 + k^2 + l^2}; \qquad \cos \mathrm{C} = \frac{2hk + l^2}{h^2 + k^2 + l^2}.$$

For the *diploid* (Fig. 118), $\cos \mathrm{A} = \frac{h^2 - k^2 + l^2}{h^2 + k^2 + l^2}$; $\qquad \cos \mathrm{C} = \frac{kl + lh + hk}{h^2 + k^2 + l^2}$.

For the *hexakistetrahedron* (Fig. 135), $\cos \mathrm{B} = \frac{h^2 - 2kl}{h^2 + k^2 + l^2}$.

II. TETRAGONAL SYSTEM.

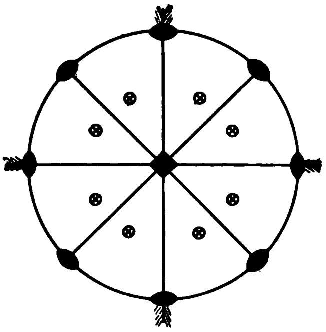
83. THE TETRAGONAL SYSTEM includes all the forms which are referred to three rectangular axes of which the two lateral axes are equal to each other and the third, the vertical axis, is either shorter or longer. The lateral axes are designated by the letter *a*; the vertical axis by *ć* (see Fig. 149). The length of the vertical axis expresses properly the axial ratio of *a* : *ć*, *a* being uniformly taken as equal to unity.

Seven groups are embraced in this system. Of these the normal group is common and important among minerals; two others have several representatives, and another a single one only. It may be noted that in four of the groups the vertical axis is an axis of tetragonal symmetry; in the remaining three it is an axis of binary symmetry only.

1. NORMAL GROUP (6). ZIRCON TYPE.

84. Symmetry.—The forms belonging to the normal group of the tetragonal system (cf. Figs. 149 to 171) have one principal plane of symmetry, the plane of the lateral axes *a*, *a*; further, at right angles to this, and meeting each other at angles of 45° in the vertical axis, *ć*, two pairs of planes of symmetry, like two-and-two. One of these sets, the axial planes, pass through the crystallographic axes, *a*, *a*, and are hence parallel to the faces lettered *a*; the others are diagonal to them, or parallel to the faces *m*.

148.



Further, the vertical axis, *ć*, is a principal axis of tetragonal symmetry; there are also four axes of binary symmetry, like two-and-two; one set coincides with the lateral axes *a*, *a*; the others are diagonal to them.

The distribution of the faces of the general form, *hkl*, belonging to this group, is shown in the spherical projection, Fig. 148.

85. Forms.—The various possible forms under the normal group of this system are as follows:

	Miller.		Naumann.
1. Base or basal pinacoid	(001)	∞ *a* : ∞ *a* : *c*	0*P* or *O*, *c*
2. Diametral prism, or prism of the second order	(100)	*a* : ∞ *a* : ∞ *c*	∞ *P* ∞ or *i-i*, *a*
3. Unit prism, or prism of the first order	(110)	*a* : *a* : ∞ *c*	∞ *P* or *I*, *m*
4. Ditetragonal prism	(*hk*0)	*a* : *na* : ∞ *c*	∞ *Pn* or *i-n*
as, (310) *i*-3; (210) *i*-2; (320) *i*-$\frac{3}{2}$, etc.			
5. Pyramids of the diametral or second order	(*h*0*l*)	*a* : ∞ *a* : *mc*	*mP* ∞ or *m-i*
as, (203) $\frac{2}{3}$-*i*; *e* (101) 1-*i*; (201) 2-*i*, etc.			

	Miller.		Naumann.
6. Pyramids of the unit, or first order,	(hhl)	$a : a : mc$	mP or m
	as, (223) $\frac{2}{3}$; (111) 1; (221) 2, etc.		
7. Ditetragonal pyramids, or Zirconoids,	(hkl)	$a : na : mc$	mPn or m-n
	as, (421) 4-2; (321) 3-$\frac{3}{2}$; (122) 1-2, etc.		

86. Basal Pinacoid or Base.—The *base* is that form which includes the two similar faces which are parallel to the plane of the lateral axes. These faces have the symbols 001 and 00$\bar{1}$ respectively; it is an "open form," as they do not inclose a space, consequently this form can occur only in combination with other forms. Cf. Figs. 149–152, etc. This form is always lettered c in this work.

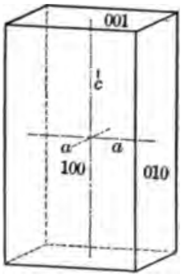
87. Prisms.—Prisms, in systems other than the isometric, have been defined to be forms whose faces are parallel to the vertical axis ($\dot{c}$) of the crystal, while they meet the two lateral axes; in this system the four-faced form whose planes are parallel both to the vertical and a lateral axis is also called a prism. There are hence three types of prisms here included.

88 Diametral Prism.—The *diametral prism* shown * in combination with the base in Fig. 149 includes the four faces which are parallel at once to the vertical and to a lateral axis; it has, therefore, the general symbol (100). It is a square prism, that is, the angle between any two adjacent faces is 90°.

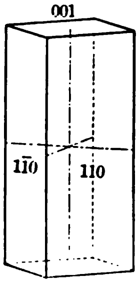
The diametral prism is often called the prism of the second order; it is uniformly designated by the letter a, and its faces, taken in order, have the symbols 100, 010, $\bar{1}$00, 0$\bar{1}$0.

It will be seen that the combination of this form with the base is the analogue of the cube of the isometric system. It has four similar vertical edges and eight similar lateral edges. It has also eight similar solid angles.

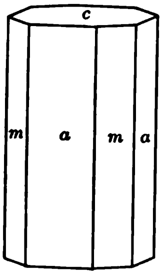
149.



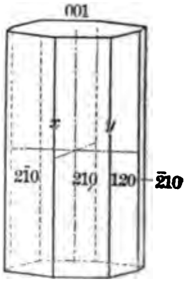
150.



151.



152.



89. Unit Prism.—The *unit prism* includes the four faces which, while parallel to the vertical axis, meet the lateral axes at equal distances; its general symbol is consequently (110). Like the preceding form, it is a square prism, with interfacial angles of 90°. It is shown in combination with the base in Fig. 150. It is often called the prism of the first order, and is uniformly designated by the letter *m*. The symbols of its faces, taken in order, are 110, 110, 110, $1\bar{1}0$.

---

* In Figs. 149–152 the dimensions of the form are made to correspond to the assumed length of the vertical axis (here $\dot{c} = 1·78$ as in octahedrite) used in Fig. 156. It must be noted, however, that in the case of actual crystals of these forms, while the tetragonal symmetry is usually indicated by the unlike physical character of the face c as compared with the faces a, m, etc., in the vertical prismatic zone, no inference can be drawn as to the relative length of the vertical axis. This last can be determined only when a pyramid is present; it is fixed for the species when a particular pyramid is chosen as fundamental or unit form, as explained later.

The faces of the unit prism truncate the edges of the diametral prism and *vice versa*. When both are equally developed, as in Fig. 151, the result is a regular eight-sided prism, which, however, it must be remembered, is a combination of *two* distinct forms.

It is evident that the two prisms described do not differ geometrically from one another, and furthermore, in a given case, the symmetry of this group allows either to be made the unit, and the other the diametral, prism according to the position assumed for the lateral axes. If on crystals of a given species both forms occur together equally developed (or, on the other hand, separately on different crystals) and without other faces than the base, there is no means of telling them apart unless by minor characteristics, as striations or other markings on the surface, etchings, etc.

90. Ditetragonal Prism.—The ditetragonal prism is the form which is bounded by eight similar faces, each one of which is parallel to the vertical axis while meeting the two lateral axes at unequal distances. It has the general symbol ($hk0$). It is shown in Fig. 152, where ($hk0$) = (210). The successive faces have here the symbols 210, 120, $\bar{1}20$, $\bar{2}10$, $\bar{2}\bar{1}0$, $\bar{1}\bar{2}0$, $1\bar{2}0$, 210.

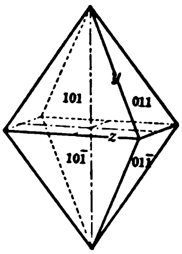
In Fig. 164 a combination is shown of this form (y = 310) with the diametral prism, the edges of which it bevels. In Fig. 168 it bevels (h = 210) the edges of the unit prism *m*. In Fig. 169 it is combined (l = 310) with both the square prisms.

91. Pyramids.—There are three types of pyramids in this group, corresponding, respectively, to the three prisms which have just been described. As already stated, the name *pyramid* is given (in systems other than the isometric) to a form whose planes meet all three of the axes; in this system the form whose planes meet the axis $\dot{c}$ and one lateral axis while parallel to the other is also a pyramid. The pyramids of this group are strictly double pyramids.

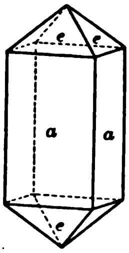
92. Diametral Pyramid.—The *diametral pyramid*, or pyramid of the second order, is the form, Fig 153, whose faces are parallel to one of the lateral axes, while meeting the other two axes. The general symbol is ($h0l$). These faces replace the basal edges of the diametral prism (Fig. 154), and the solid angles of the unit prism (cf. Fig. 155). It is a square pyramid (also called a square octahedron), since its basal section is a square, and the interfacial angles over the four terminal edges, above and below, are equal. The successive faces of the form (101) are as follows: Above 101, 011, $\bar{1}01$, $0\bar{1}1$; below $10\bar{1}$, $01\bar{1}$, $\bar{1}0\bar{1}$, $0\bar{1}\bar{1}$.

If the ratio of the intercepts on the lateral and vertical axes is the assumed axial ratio of the species, the symbol is (101), and the form is designated by the letter *e*. This ratio can be deduced from the measurement of either one of the interfacial angles (y or z) over the terminal or basal edges, as explained later. In the case of a given species, a number of diametral pyramids may occur, varying in the ratio of the axes a and $\dot{c}$. Hence there is possible an indefinite number of such forms whose symbols may be, for example, (104), (103), (102), (101), (302), (201), (301), etc. Those mentioned first come nearest to the base (001), those last to the diametral prism (100); the base is therefore the limit of these pyramids ($h0l$) when h = 0, and the diametral prism (100) when $h = \infty$ and $l = 1$; or, what is the same thing, when $h = 1$ and $l = 0$. Fig. 165 shows the three diametral pyramids *u* (105), *e* (101), *q* (201).

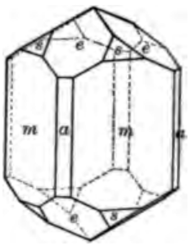
153.



154.



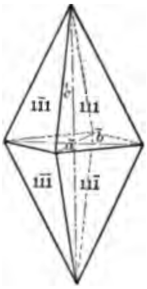
155.



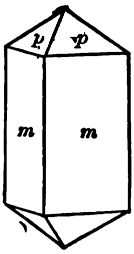
Rutile.

93. Unit Pyramid.—A *unit pyramid*, or pyramid of the first order, is a form whose eight similar faces intersect the two lateral axes at equal distances and also intersect the vertical axis. It has the general symbol (*hhl*). Like the diametral pyramid, it is a square pyramid (or square octahedron) with equal interfacial angles over the terminal edges, and the faces replace the lateral, or basal, edges of the unit prism. If the ratio of the vertical to the lateral axis for a given unit pyramid is the assumed axial ratio for the species, the form is called the *fundamental form*, and it has the symbol (111) as in Fig. 156. Its faces mentioned in order as before are: Above 111, $\bar{1}11$, $\bar{1}\bar{1}1$, $1\bar{1}1$; below $11\bar{1}$, $\bar{1}1\bar{1}$, $\bar{1}\bar{1}\bar{1}$, $1\bar{1}\bar{1}$.

156.

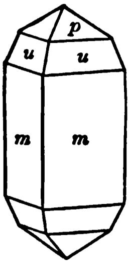


157.



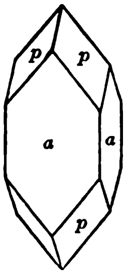
Zircon.

158.



Zircon.

159.



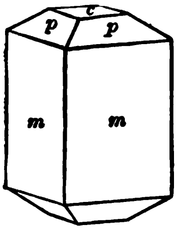
Apophyllite

Obviously the angles of the unit pyramid, and hence its geometrical aspect, vary widely with the length of the vertical axis. For Fig. 156 (octahedrite) $\dot{c} = 1{\cdot}78$; for Fig. 161 $p = (111)$ and $\dot{c} = 0{\cdot}64$.

For a given species there may be a number of unit pyramids, varying in position according to the ratio of the vertical to the lateral axis. Their symbols, passing from the base (001) to the unit prism (110), may thus be (115), (113), (223), (111), (332), (221), (441), etc. In the general symbol of these forms (*hhl*), as *h* diminishes, the form approximates more and more nearly to the base (001), for which $h = 0$; as *h* increases, the form passes toward the unit prism, for which $h = \infty$ if $l = 1$, that is, for which $h = 1$ if $l = 0$. In Fig. 158 two pyramids of this order are shown, *p* (111) and *u* (331).

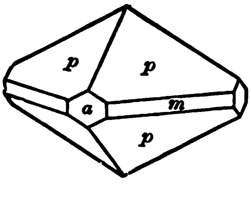
The faces of the unit pyramids replace the terminal edges of the unit prism (Figs. 157, 160) and the solid angles of the diametral prism (Fig. 159).

160.



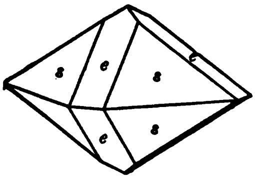
Vesuvianite.

161.



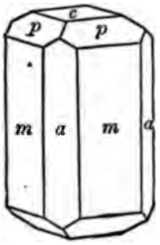
Vesuvianite.

162.



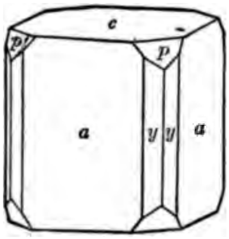
Cassiterite.

163.



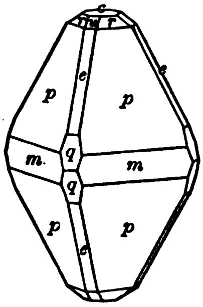
Vesuvianite.

164.



Apophyllite.

165.



Octahedrite.

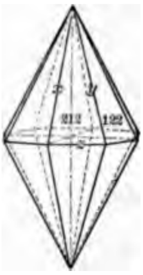
The application of the zonal relations proves that a diametral pyramid truncating the pyramidal edges of a given unit pyramid has the *same* ratio as it has for *h* to *l*. Thus (101) truncates the terminal edge of (111); (201) of (221), etc. Again, if a unit pyramid truncates the pyramidal edges of a given diametral pyramid, its ratio for *h* to *l* is *half* that of the other form; that is, (112) truncates the pyramidal edges of (101); (111) of (201), etc. These relations are exhibited by Fig. 165, and the basal and spherical projections (Figs. 170, 171) corresponding to it. Here *e* (101) and *u* (105) truncate the terminal edges of *p* (111) and *r* (115), respectively, while *p* (111) truncates the edges of *q* (201).

94. Ditetragonal Pyramid, or Zirconoid.—The *ditetragonal pyramid*, or double eight-sided pyramid, is the form each of whose sixteen similar faces meets the three axes at unequal distances. This is the most general case of the symbol (*hkl*), where *h*, *k*, *l* are all unequal and no one is equal to 0. That there are sixteen faces in a single form is evident. Thus, for example, for the form (212) the face 212 is similar to 122, the two lateral axes being equal (not, however, to 221). Hence there are two like faces in each octant. Similarly the symbols of all the faces in the successive octants are, therefore, as follows:

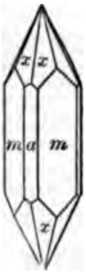
Above	212	122	$\bar{1}22$	$\bar{2}12$	$\bar{1}\bar{2}2$	$\bar{1}\bar{2}2$	$1\bar{2}2$	$2\bar{1}2$
Below	$21\bar{2}$	$12\bar{2}$	$\bar{1}2\bar{2}$	$\bar{2}1\bar{2}$	$\bar{2}\bar{1}\bar{2}$	$\bar{1}\bar{2}\bar{2}$	$1\bar{2}\bar{2}$	$2\bar{1}\bar{2}$

This form is common with the species zircon, and is hence often called a *zirconoid*. It is shown in Fig. 166. It is not observed alone, though sometimes, as in Figs 167 (x = 311) and 168 (z = 321), it is the predominating form. In Fig. 169 two zirconoids occur, namely, t (313) and z (321). Cf. also Figs. 6, 8, 9 of zircon on p. 8.

166.

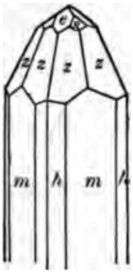


167.



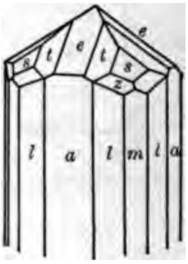
Zircon.

168.



Cassiterite.

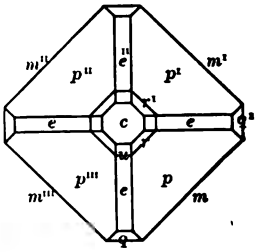
169.



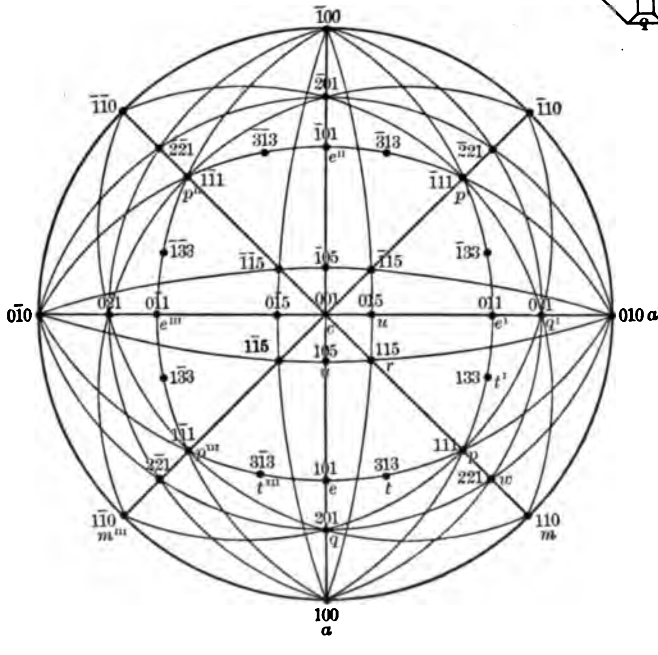
Rutile

95. In addition to the perspective figures already given, a basal projection (Fig 170) is added of the crystal of octahedrite already referred to (Fig. 165); also a spherical projection of the same (Fig. 171) with the faces of the form (313) added. These exhibit well the general relations of this normal group of the tetragonal system. The symmetry here is to be noted, first, with respect to the similar zones 100, 001, $\bar{1}00$ and 010, 001, $0\bar{1}0$; also, second, that of the other pair of similar zones, 110, 001, $\bar{1}\bar{1}0$, and $1\bar{1}0$, 001, $\bar{1}10$.

170.



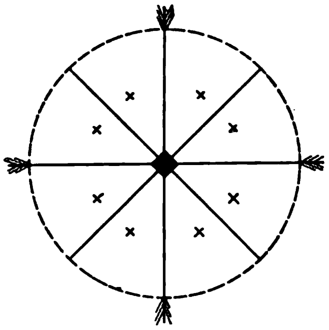
171.



2. HEMIMORPHIC GROUP (7).

96. Symmetry.—This group differs from the normal group only in having no plane of symmetry through the plane of the transverse axes; hence the forms are hemimorphic as defined in Art. **29.** It is not known to be represented among minerals, and is sufficiently illustrated by the spherical projection (Fig. 172). Here the two basal planes are distinct forms, 001 and 00$\bar{1}$; the prisms do not differ geometrically from those of the normal group, though distinguished by their molecular structure; further, the pyramids are no longer double pyramids, but each form is represented by one half of Figs. 153, 156, 166 (cf Fig. 50, p 18). There are hence six distinct pyramidal forms, corresponding to the upper and lower halves of the unit pyramid, the diagonal pyramid and the ditetragonal pyramid.

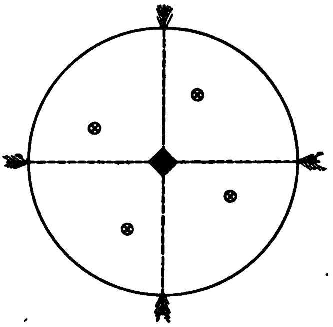
172.



3. PYRAMIDAL GROUP (8). SCHEELITE TYPE.

97. Typical Forms and Symmetry.—The forms here included have one plane of symmetry only, that of the transverse axes, and one axis of tetragonal symmetry (the vertical axis) normal to it. The distinct forms are the tetragonal prism ($hk0$) and pyramid (hkl) of the *third order*, shown in Figs. 174, 175.

173.



The distribution of the faces of the general form (hkl) on the spherical projection, Fig. 173, exhibits the symmetry of the group. Comparing this, as well as the figures immediately following, with those of the normal group, it is seen that this group differs from it in the absence of the vertical planes of symmetry and the horizontal axes of symmetry. Further, half the faces, belonging to each octant, of the normal form (hkl) shown in Fig. 166 only are present, and these are the faces situated in a vertical zone, from 001 to 00$\bar{1}$.

98. Prism and Pyramid of the Third Order.—The typical forms of the group, as above stated, are a square prism and a square pyramid, which are distinguished respectively from the square prisms *a* (100) and *m* (110), shown in Figs. 149 and 150, and from the square pyramids ($h0l$) and (hhl) of Figs. 153 and 156 by the name "third order."

There are two complementary forms in each case, designated *left* and *right*, which together include all the faces of the ditetragonal prism (Fig. 152) and ditetragonal pyramid (Fig. 166) of the normal group

The faces of the two complementary prisms, as (210), are:

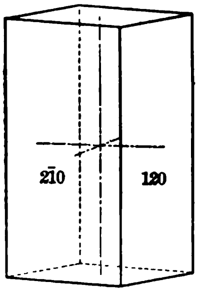
Left: 210, $\bar{1}20$, $\bar{2}\bar{1}0$, $1\bar{2}0$.
Right: 120, $\bar{2}10$, $\bar{1}\bar{2}0$, $2\bar{1}0$.

The faces of the corresponding pyramids, as (212), are:

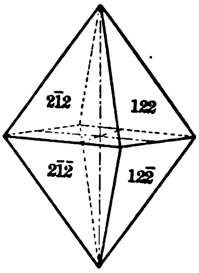
Left: above 212, $\bar{1}22$, $\bar{2}\bar{1}2$, $1\bar{2}2$; below $21\bar{2}$, $\bar{1}2\bar{2}$, $\bar{2}\bar{1}\bar{2}$, $1\bar{2}\bar{2}$.
Right: above 122, $\bar{2}12$, $\bar{1}\bar{2}2$, $2\bar{1}2$; below $12\bar{2}$, $\bar{2}1\bar{2}$, $\bar{1}\bar{2}\bar{2}$, $2\bar{1}\bar{2}$.

Fig. 176 gives a transverse section of the prisms *a* (100) and *m* (110), also the prism of the third series (120). Fig. 175 shows the right pyramid (122) corresponding to the same prism.

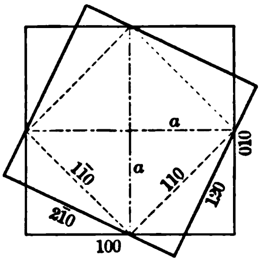
174.



175.



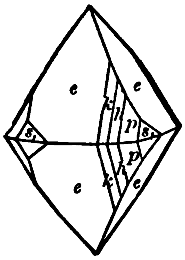
176.



99. Other Forms.—The other forms of this group, that is, the base *c* (001); the other square prisms, *a* (100) and *m* (110); also the square pyramids (*h0l*) and (*hhl*) are geometrically like the corresponding forms of the normal group already described.

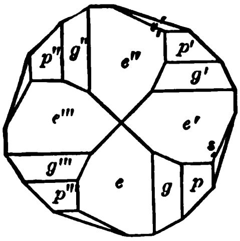
100. To this group belongs the important species scheelite; also the isomorphous species stolzite and powellite, unless it be that they are rather to be classed with wulfenite (p. 61). Fig. 177 shows a typical crystal of scheelite, and Fig. 178 a basal section of one similar; these illustrate well the characteristics of the group. Here the forms are *e* (101), *p* (111), and the third-order pyramids *k* (515), *h* (313), *g* (212), *s*, (131). Fig. 179 represents a meionite crystal with *r* (111) and the third-order pyramid *z* (311) See also Figs. 181, 182, in which the third-order prism is shown.

177.



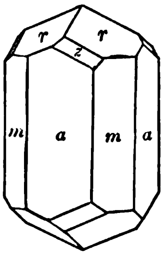
Scheelite.

178.



Scheelite.

179.

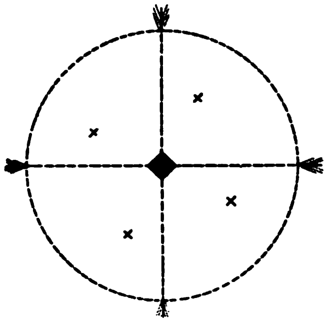


Meionite.

The forms of this group are sometimes described (see Art. **28**) as showing *pyramidal hemihedrism ;* hence the name here given.

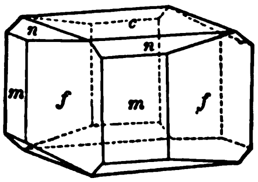
4. PYRAMIDAL-HEMIMORPHIC GROUP (9). WULFENITE TYPE.

180.

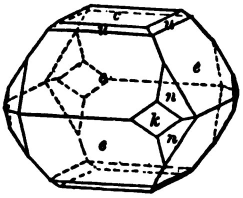


101. Symmetry.—The fourth group of the tetragonal system is closely related to the group just described. It has the same vertical axis of tetragonal symmetry, but there is no transverse plane of symmetry. The forms are, therefore, hemimorphic in the distribution of the faces (cf. Fig. 180). The species wulfenite of the Scheelite Group among mineral species probably belongs here, although the crystals do not always show the difference between the pyramidal faces, above and below, which would characterize distinct complementary forms. Figs. 181, 182 could, therefore, serve as illustrations of the preceding group, but in Fig. 183 a characteristic distinction is exhibited. In these figures the forms are *u* (102), *e* (101), *n* (111); also *f* (230), *k* (210), *z* (432), *x* (311).

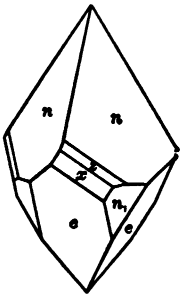
181.



182.



183.

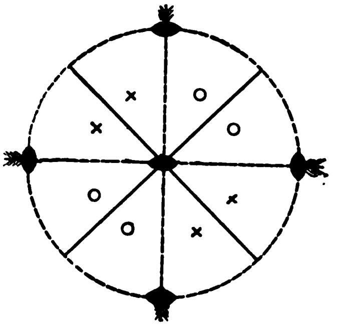


Figs. 181–183, Wulfenite.

5. SPHENOIDAL GROUP (10). CHALCOPYRITE TYPE.

102. Typical Forms and Symmetry.—The typical forms of this group are the sphenoid (Fig. 185) and the tetragonal scalenohedron (Fig. 186). They and all the combinations of this group are characterized by the presence of two vertical planes of symmetry; these are diagonal to the crystallographic axes and intersect at angles of 90° in the vertical axis, which is an axis of binary symmetry only. Further, the two horizontal crystallographic axes are axes of binary symmetry.

184.



This symmetry is exhibited in the distribution of the faces of the general form (*hkl*) in the spherical projection (Fig. 184). It is seen here that the faces are present in the alternate octants only, and it will be remembered that this same statement was made of the tetrahedral group under the isometric system. There is hence a close analogy between these two groups. The symmetry of this group should be carefully compared with that of the first and third groups of this system already described.

103. Sphenoid.—The sphenoid, shown in Fig. 185, is a four-faced solid, resembling a tetrahedron, but each face is an isosceles (not an equilateral) triangle. The general symbol of the plus unit sphenoid is (111), and the faces have the symbols: 111, $\bar{1}\bar{1}1$, $\bar{1}1\bar{1}$, $1\bar{1}\bar{1}$. The complementary minus sphenoid has the symbol ($1\bar{1}1$), and these two forms include all the faces of the unit pyramid (111) of the normal group. When they occur together, if equally developed, the resulting solid, though having two unlike sets of faces, cannot be distinguished geometrically from the square pyramid (111).

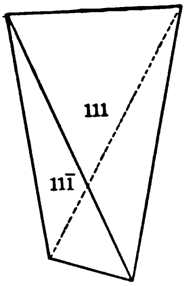
In the species chalcopyrite, which belongs to this group, the deviation in angle and in axial ratio from the isometric system is very small, and hence the unit sphenoid cannot by the eye be distinguished from a tetrahedron (compare Fig. 187 with Fig. 128, p. 47). For this species $\dot{c}$ = 0·985 (instead of 1, as in the isometric system), and the normal sphenoidal angle is 108° 40′, instead of 109° 28′, the angle of the tetrahedron. Hence a crystal with both the plus and minus sphenoids equally developed closely resembles a regular octahedron.

In Fig 188 the diametral pyramids *e* (101) and *z* (201) are also present, also the base *c* (001).

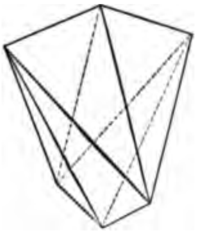
104. Tetragonal Scalenohedron.—The sphenoidal symmetry yields another distinct type of form, that shown in Fig. 186. It is bounded by eight similar scalene triangles, and hence is called a tetragonal scalenohedron; the general symbol is (*hkl*). The faces of the complementary plus and minus forms embrace all the faces of the ditetragonal pyramid This form appears in combination in chalcopyrite, but is not observed independently. In Fig. 189 the form *s* (531) is the plus tetragonal scalenohedron.

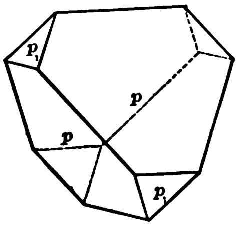
105. Other Forms.—The other forms of the group, namely, the two square prisms, the ditetragonal prism, and the two square pyramids (*hhl*) and (*h0l*), are geometrically like those of the normal group. The lower symmetry in the molecular structure is only revealed by special investigation, as by etching.

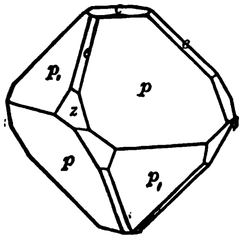
185.

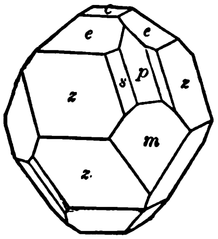


186.







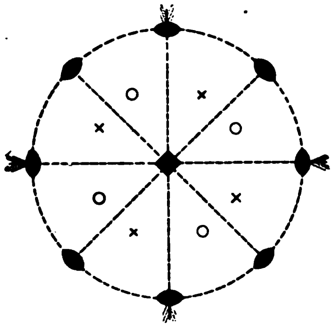


Figs. 187-189, Chalcopyrite.

6. TRAPEZOHEDRAL GROUP (11).

106. The trapezohedral group is analogous to the plagihedral group under the isometric system; it is characterized by the absence of any plane or center of symmetry; the vertical axis, however, is an axis of tetragonal symmetry, and perpendicular to this there are four axes of binary symmetry. The distribution of the faces of the general form (*hkl*) is shown in the spherical projection,

190.



191.

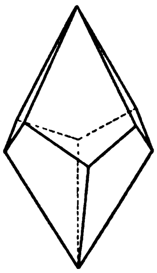


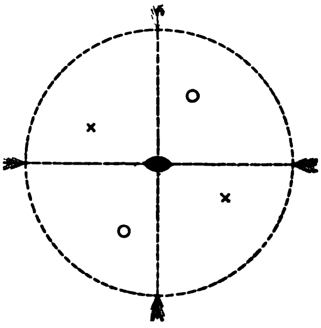
Fig. 190, and Fig. 191 gives the resulting solid, a *tetragonal trapezohedron.* The complementary right- and left-handed forms embrace all the faces of the ditetragonal pyramid of the normal group. These two forms are enantiomorphous, and the salts belonging to this group show circular polarization.

Phosgenite (p. 364) probably belongs to this group (Goldschmidt).

7. TETARTOHEDRAL GROUP (12).

107. Symmetry.—The seventh and last possible group under this system has no plane nor center of symmetry, but the vertical axis is an axis of binary symmetry. The distribution of the faces of the general form (*hkl*) is shown on the sphere of projection (Fig. 192), and the solid resulting is a sphenoid of the third order. There are also three other possible forms complementary to this, and the four are respectively distinguished as right (+ and —) and left (+ and —). These four together embrace all the sixteen faces of the ditetragonal pyramid. The other characteristic forms of this group are the prism of the third order (*hk*0), the plus and minus sphenoids of the first order (111), and also those of the second order (101). This group has no known representative.

192.



MATHEMATICAL RELATIONS OF THE TETRAGONAL SYSTEM.

108. Choice of Axes.—It appears from the discussion of the symmetry of the seven groups of this system that with all of them the position of the vertical axis is fixed. In groups 1, 2, however, where there are two sets of vertical planes of symmetry, either set may be made the axial planes and the other the diagonal planes. The choice between these two possible positions of the lateral axes is guided particularly by the habit of the occurring crystals and the relations of the given species to others of similar form.

109. Determination of the Axial Ratio, etc.—The following relations serve to connect the axial ratio, that is, the length of the vertical axis $\dot{c}$, when $a = 1$, with the fundamental angles $(001 \wedge 101)$ and $(001 \wedge 111)$:

$$\tan(001 \wedge 101) = \dot{c}; \qquad \tan(001 \wedge 111) \times \frac{1}{2}\sqrt{2} = \dot{c}.$$

For faces in the same rectangular zone the tangent principle applies. The most important cases (cf. Fig. 171) are:

$$\frac{\tan(001 \wedge h0l)}{\tan(001 \wedge 101)} = \frac{h}{l};$$

$$\frac{\tan(001 \wedge 0kl)}{\tan(001 \wedge 011)} = \frac{k}{l};$$

$$\frac{\tan(001 \wedge hhl)}{\tan(001 \wedge 111)} = \frac{h}{l}.$$

For the prisms

$$\tan(010 \wedge hk0) = \frac{h}{k}, \qquad \text{or} \qquad \tan(100 \wedge hk0) = \frac{k}{h}.$$

110. Other Calculations.—It will be noted that in the spherical projection (Fig. 171) all those spherical triangles are right-angled which are formed by great circles (diameters) which meet the prismatic zone-circle 100, 010, $\bar{1}00$, $0\bar{1}0$. Again, all those formed by great circles drawn between 100 and $\bar{1}00$, or 010 and $0\bar{1}0$, and crossing respectively the zone-circles 100, 001, $\bar{1}00$, or 010, 001, $0\bar{1}0$. Also, all those formed by great circles drawn between 110 and $\bar{1}\bar{1}0$ and crossing the zone-circle $\bar{1}10$, 001, $1\bar{1}0$, or between $\bar{1}10$ and $1\bar{1}0$ and crossing the zone-circle 110, 001, $\bar{1}\bar{1}0$.

These spherical triangles may hence be readily used to calculate any angles desired; for example, the angles between the pole of any face, as *hkl* (say 321), and the pinacoids 100, 010, 001. The terminal angles (*x* and *z*, Fig. 166) of the ditetragonal pyramid, $212 \wedge 2\bar{1}2$ (or $313 \wedge 3\bar{1}3$, etc.), and $212 \wedge 122$ (or $313 \wedge 133$, etc.), can also be obtained in the same way. The zonal relations give the symbols of the poles on the zones 001, 100 and 001, 110 for the given case. For example, the zone-circle $1\bar{1}0$, 313, 133, $\bar{1}10$ meets $\bar{1}\bar{1}0$, 001, 110 at the pole 223, and the calculated angle $313 \wedge 223$ is half the angle $313 \wedge 133$. If a large number of similar angles are to be calculated, it is more convenient to use a formula, as that given below.

111. Formulas.—It is sometimes convenient to have the normal interfacial angles expressed directly in terms of the axis $\dot{c}$ and the indices *h*, *k*, and *l*. Thus:

(1) The distances of the pole of any face P (*hkl*) from the pinacoids *a* (100) = P*a*, *b* (010) = P*b*, *c* (001) = P*c* are given by the following equations:

$$\cos^2 Pa = \frac{h^2c^2}{h^2c^2 + k^2c^2 + l^2}; \quad \cos^2 Pb = \frac{k^2c^2}{h^2c^2 + k^2c^2 + l^2}; \quad \cos^2 Pc = \frac{l^2}{h^2c^2 + k^2c^2 + l^2}.$$

These may also be expressed in the form

$$\tan^2 Pa = \frac{k^2c^2 + l^2}{h^2c^2}; \quad \tan^2 Pb = \frac{h^2c^2 + l^2}{k^2c^2}; \quad \tan^2 Pc = \frac{h^2c^2 + k^2c^2}{l^2}.$$

(2) For the distance between the poles of any two faces (*hkl*), (*pqr*), we have in general

$$\cos PQ = \frac{hpc^2 + kqc^2 + lr}{\sqrt{[(h^2 + k^2)c^2 + l^2][(p^2 + q^2)c^2 + r^2]}}.$$

The above equations take a simpler form for special cases often occurring; for example, for *hkl* and the angle of the edge *y* of Fig. 166.

112. Prismatic Angles.—The angles for the commonly occurring ditetragonal prisms are as follows:

	Angle on *a* (100, *i-i*)	Angle on *m* (110, *I*)		Angle on *a* (100, *i-i*)	Angle on *m* (110, *I*)
410, *i*-4	14° 2¼′	30° 57¾′	530, *i*-$\frac{5}{3}$	30° 57¾′	14° 2¼′
310, *i*-3	18 26	26 34	320, *i*-$\frac{3}{2}$	33 41½	11 18¾
210, *i*-2	26 34	18 26	430, *i*-$\frac{4}{3}$	36 52¼	8 7¾

III. HEXAGONAL SYSTEM.

113. The HEXAGONAL SYSTEM includes all the forms which are referred to four axes, three equal lateral axes in a common plane intersecting at angles of 60°, and a fourth, vertical axis, at right angles to them.

Two sections are here included, each embracing a number of distinct groups related among themselves. They are called the *Hexagonal Division* and the *Trigonal* (or *Rhombohedral*) *Division*. The symmetry of the former, about the vertical axis, belongs to the hexagonal type, that of the latter to the trigonal type.

Miller (1852) referred all the forms of the hexagonal system to three equal axes parallel to the faces of the fundamental rhombohedron, and hence intersecting at equal angles, not 90°. This method (further explained in Art. 168) has the disadvantage of failing to bring out the relationship between the normal hexagonal and tetragonal types, both characterized by a principal axis of symmetry, which (on the system here adopted) is the vertical crystallographic axis. It further gives different symbols to faces which are crystallographically identical. It is more natural to employ the three rhombohedral axes for trigonal forms only, as done by Groth (1894), who includes these groups in a *Trigonal System;* but this also has some disadvantages.

114. Groups.—There are five possible groups in the Hexagonal Division. Of these the normal group is much the most important, and two others are also of importance among crystallized minerals.

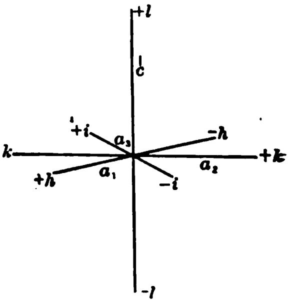
In the Trigonal Division there are seven groups; of these the rhombohedral group or that of the Calcite Type is by far the most common, and three others are also of importance.

115. Axes and Symbols:—The position of the four axes taken is shown in Fig. 193; the three lateral axes are called a, and the vertical axis is $\dot{c}$. Further, when it is desirable to distinguish between the lateral axes they may be designated a_1, a_2, a_3. The general position of any plane on the method of Bravais (who adapted the system of Miller to this system) may be expressed in a manner analogous to that applicable in the other systems, viz.:

$$\frac{1}{h}a_1 : \frac{1}{k}a_2 : \frac{1}{i}a_3 : \frac{1}{l}\dot{c}.$$

The corresponding indices for a given plane are then h, k, i, l; these always refer to the axes named in the above scheme:

193.



It is found convenient to consider the axis a_3 as negative in front and positive behind, hence the general symbol is $hk\bar{i}l$. Further, as following from the angular relation of the three lateral axes, it can be readily shown to be always true that the algebraic sum of the indices h, k, i, is equal to zero:

$$h + k + i = 0.$$

The general expression for any plane in accordance with the system of Naumann is

$$na : pa : -a : ma.$$

Here it is always true that $p = \frac{n}{n-1}$. The shortened form for the above expression as adopted by Naumann is mPn.

The relation of Miller's indices to those of Naumann is obvious if for a given plane with the symbol, say, $21\bar{3}1$ the parameters are given in full, namely:

$$\frac{1}{2}a_1 : 1a_2 : -\frac{1}{3}a_3 : 1c. \tag{1}$$

This is equivalent (after multiplying by 3) to

$$\frac{3}{2}a_1 : 3a_2 : -1a_3 : 3c. \tag{2}$$

Here $m = 3$, $n = \frac{3}{2}$, and the value of p is 3. The symbol is hence written

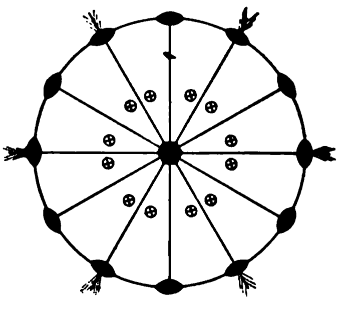
$$3P\frac{3}{2}, \text{ or } 3\text{-}\frac{3}{2}.$$

A. Hexagonal Division.

1. NORMAL GROUP (13). BERYL TYPE.

116. Symmetry.—Crystals belonging to the normal group of the Hexagonal Division have one principal plane of symmetry, the plane of the lateral axes; also, normal to this and meeting in the vertical axis at angles of 30°, six other planes of symmetry, like three-and-three. Those of one set pass through the lateral axes *a, a, a* (Figs. 195, 198) and are hence parallel to the faces of the form (10$\bar{1}$0) lettered *m*, as in Fig. 208. The others are diagonal to the first set (Figs. 196, 198) and are parallel to the faces of the form (11$\bar{2}$0) lettered *a*, Fig. 208.

194.



Further, these crystals have one principal axis of hexagonal, or sixfold, symmetry, the vertical crystallographic axis; also six horizontal axes of binary symmetry; three of these coincide with the lateral crystallographic axes, the others are diagonal to them. The symmetry of this group is exhibited in the accompanying spherical projection, Fig. 194, and by the figures in the following pages from 195 to 209.

The analogy between this group and the normal group of the tetragonal system is obvious at once and will be better appreciated as greater familiarity is gained with the individual forms and their combinations.

117. Forms.—The possible forms in this group are as follows:

	Miller-Bravais.		Naumann.
1. Base....................	(0001)	$\infty a : \infty a : \infty a : c$	$0P$ or O, c
2. Unit prism, or prism of the first order	(10$\bar{1}$0)	$a : \infty a : -a : \infty c$	∞P or I, m
3. Diagonal prism, or prism of the second order	(11$\bar{2}$0)	$2a : 2a : -a : \infty c$	$\infty P2$ or i-2, *a*

	Miller-Bravais.		Naumann.
4. Dihexagonal prism........	$(hk\bar{i}0)$	$na : pa : -a : \infty c$	∞Pn or i-n
	as, $(21\bar{3}0)$	$\frac{3}{2}a : 3a : -a : \infty c$	$\infty P\frac{3}{2}$ or i-$\frac{3}{2}$
5. Pyramids of the unit, or first order ...	$(h0\bar{h}l)$	$a : \infty a : -a : mc$	mP or m
	as, $(10\bar{1}1)$	$a : \infty a : -a : c$	P or 1;
	also $20\bar{2}1$	$(a : \infty a : -a : 2c)$	$2P$ or 2
6. Diagonal pyramids, or pyramids of the second order	$(h{\cdot}h{\cdot}2\bar{h}{\cdot}l)$	$2a : 2a : -a : mc$	$mP2$ or m-2
	as, $(11\bar{2}2)$	$2a : 2a : -a : c$	$P2$ or 1-2
7. Dihexagonal pyramids, or berylloids	$(hk\bar{i}l)$	$na : pa : -a : mc$	mPn or m-n
	as, $(21\bar{3}1)$	$\frac{3}{2}a : 3a : -a : 3c$	$3P\frac{3}{2}$ or 3-$\frac{3}{2}$

In the above $h > k$, and $h + k = -i$.

118. Base—The *base*, or *basal pinacoid*, includes the two faces, 0001 and $000\bar{1}$, parallel to the plane of the lateral axes. It is uniformly designated by the letter c; see Figs. 195 *et seq.*

119. Prisms. Unit Prism.—There are three types of prisms, or forms in which the faces are parallel to the vertical axis.

The *unit prism*, or prism of the first order, Fig. 195, includes six faces, each one of which is parallel to the vertical axis and meets two adjacent lateral axes at equal distances, while it is parallel to the third lateral axis. It has hence the general symbol $(10\bar{1}0)$ and is uniformly designated by the letter m; its six faces, taken in order (see Figs. 195 and 209), are:

$10\bar{1}0$, $01\bar{1}0$, $\bar{1}100$, $\bar{1}010$, $0\bar{1}10$, $1\bar{1}00$.

120. Diagonal Prism.—The *diagonal prism*, or prism of the second order, Fig 196, has six faces, each one of which is parallel to the vertical axis, and meets the three lateral axes, the two alternate at the unit distance, the other at one-half this distance; or, which is the same thing, it meets the last-named axis at the unit distance, the others at double this distance.* The general symbol is $(11\bar{2}0)$ and it is uniformly designated by the letter a; the six faces (see Figs 196 and 209) in order are :

$11\bar{2}0$, $\bar{1}2\bar{1}0$, $\bar{2}110$, $\bar{1}\bar{1}20$, $1\bar{2}10$, $2\bar{1}\bar{1}0$.

The unit prism and the diagonal prism are not to be distinguished geometrically, each being a regular hexagonal prism with normal interfacial angles of 60°. They are related to each other in the same way as the two square prisms m (110) and a (100) of the tetragonal system.

The relation in position between the unit prism (and pyramids) on the one hand and the diagonal prism (and pyramids) on the other will be understood better from Fig. 198, representing a cross-section parallel to the base c.

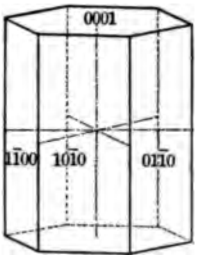
121. Dihexagonal Prism.—The *dihexagonal prism*, Fig. 197, is a twelve-sided prism bounded by twelve faces, each one of which is parallel to the vertical axis, and also meets two adjacent lateral axes at unequal distances the ratio of which always lies between 1 : 1 and 1 : 2 (see 2 p. 66). This prism has two unlike edges, lettered x and y, as shown in Fig. 197. The general symbol is $(hk\bar{i}0)$, and the faces of a given form, as $(21\bar{3}0)$, are:

$21\bar{3}0$, $12\bar{3}0$, $\bar{1}3\bar{2}0$, $\bar{2}3\bar{1}0$, $\bar{3}2\bar{1}0$, $\bar{3}120$,
$\bar{2}130$, $\bar{1}\bar{2}30$, $1\bar{3}20$, $2\bar{3}10$, $3\bar{2}\bar{1}1$, $3\bar{1}\bar{2}0$.

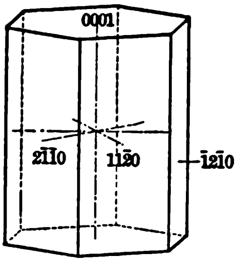
---

* Since $1a_1 : 1a_2 : -\frac{1}{2}a_3 : \infty c$ is equivalent to $2a_1 : 2a_2 : -1a_3 : \infty c$.

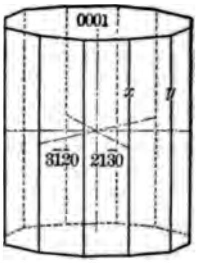
195.



196.



197.



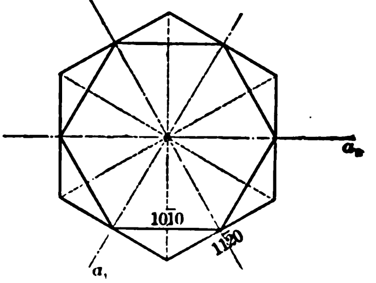
122. Pyramids. Unit Pyramids.—Corresponding to the three types of prisms just mentioned, there are three types of pyramids.

A *unit pyramid*, or pyramid of the first order, Fig. 199, is a form bounded by twelve similar triangular faces—six above and six below—which have the same position relative to the lateral axes as the faces of the unit prism, while they also intersect the vertical axis. The general symbol is hence $(h0\bar{h}l)$. The faces of a given form, as $(10\bar{1}1)$, are:

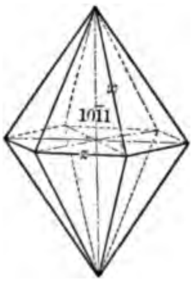
Above $10\bar{1}1$, $01\bar{1}1$, $\bar{1}101$, $\bar{1}011$, $0\bar{1}11$, $1\bar{1}01$.
Below $10\bar{1}\bar{1}$, $01\bar{1}\bar{1}$, $\bar{1}10\bar{1}$, $\bar{1}01\bar{1}$, $0\bar{1}1\bar{1}$, $1\bar{1}0\bar{1}$.

On a given species there may be a number of unit pyramids, differing in the ratio of the lateral to the vertical axis, and thus forming a zone between the base (0001) and the faces of the unit prism $(10\bar{1}0)$. Their symbols, passing from the base (0001) to the unit prism $(10\bar{1}0)$, would be, for example, $10\bar{1}4$, $10\bar{1}2$, $20\bar{2}3$, $10\bar{1}1$, $30\bar{3}2$, $20\bar{2}1$, etc. In Fig. 202, the faces *o* and *s* are unit pyramids and they have the symbols respectively $(10\bar{1}1)$ and $(20\bar{2}1)$, here $\dot{c} = 1{\cdot}014$. In Fig. 205, *p* is the unit pyramid $(10\bar{1}1)$; here $\dot{c} = 0{\cdot}50$. As shown in these cases the faces of the unit pyramids replace the edges of the unit prism. On the other hand, they replace the solid angles of the diagonal prism *a* $(11\bar{2}0)$ as shown in Fig. 204.

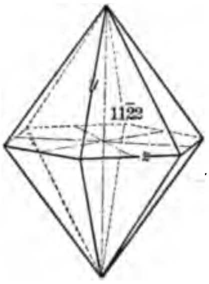
198.



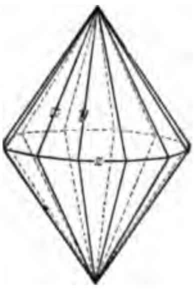
199.



200.



201.

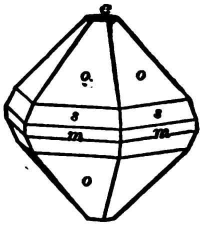


123. Diagonal Pyramids.—The *diagonal pyramid*, or pyramid of the second order (Fig. 200), is a double six-sided pyramid including the twelve similar faces which have the same position relative to the lateral axes as the faces of the diagonal prism, and which also intersect the vertical axis. They have the general symbol $(h \cdot h \cdot 2\bar{h} \cdot l)$. The symbols of the faces of the form $(11\bar{2}2)$ are:

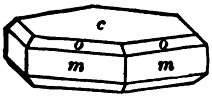
Above $11\bar{2}2$, $\bar{1}2\bar{1}2$, $\bar{2}112$, $\bar{1}\bar{1}22$, $1\bar{2}12$, $2\bar{1}\bar{1}2$.
Below $11\bar{2}\bar{2}$, $\bar{1}2\bar{1}\bar{2}$, $\bar{2}11\bar{2}$, $\bar{1}\bar{1}2\bar{2}$, $1\bar{2}1\bar{2}$, $2\bar{1}\bar{1}\bar{2}$.

The faces of the diagonal pyramid replace the edges between the faces of the diagonal prism and the base. Further, they replace the solid angles of the unit prism *m* $(10\bar{1}0)$. There may be on a single crystal a number of diagonal pyramids forming a zone between the base *c* (0001) and the faces of the diagonal prism *a* $(11\bar{2}0)$, as, naming them in order: $11\bar{2}4$, $11\bar{2}2$, $22\bar{4}3$, $11\bar{2}1$, etc. In Fig 205, *o*, *s* are the diagonal pyramids $(11\bar{2}2)$ and $(11\bar{2}1)$.

202.

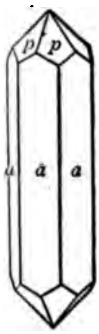


203.



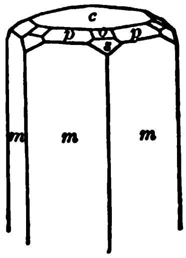
Hanksite.

204.



Connellite.

205.



Beryl.

124. Dihexagonal Pyramid.—The *dihexagonal pyramid*, Fig. 201, is a double twelve-sided pyramid, having the twenty-four similar faces embraced under the general symbol (*hkil*). It is bounded by twenty-four similar faces, each meeting the vertical axis and having a ratio for the intercepts on two adjacent lateral axes between 1 : 1 and 1 : 2 (cf. the general symbol (2) given in Art. **115**). Thus the form $(21\bar{3}1)$ includes the following twelve faces in the upper half of the crystal:

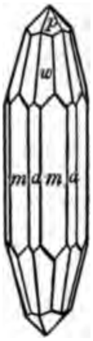
$21\bar{3}1$, $12\bar{3}1$, $\bar{1}3\bar{2}1$, $\bar{2}3\bar{1}1$, $\bar{3}211$, $\bar{3}121$,
$\bar{2}\bar{1}31$, $\bar{1}\bar{2}31$, $1\bar{3}21$, $2\bar{3}11$, $3\bar{2}\bar{1}1$, $3\bar{1}\bar{2}1$.

And similarly below with *l* (here 1) negative, $21\bar{3}\bar{1}$, etc. The dihexagonal pyramid is often called a *berylloid* because a common form with the species beryl. In Fig 206, *w* is the berylloid $(11 \cdot 2 \cdot \bar{13} \cdot 3)$.

125. Combinations.—Fig. 207 of beryl shows a combination of the base *c* (0001) and prism *m* $(10\bar{1}0)$ with the unit pyramids *p* $(10\bar{1}1)$ and *u* $(20\bar{2}1)$; the diagonal pyramid *s* $(11\bar{2}1)$ and the berylloids *v* $(21\bar{3}1)$ and *n* $(31\bar{4}1)$. Both the last forms lie in a zone between *m* and *s*, for which it is true that $k = l$.

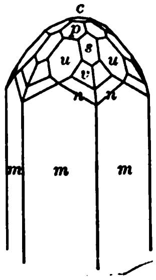
The basal projection of a similar crystal shown in Fig. 208 is very instructive as exhibiting the symmetry of the normal hexagonal group. This is also true of the spherical projection in Fig. 209 of a like crystal with also the form *o* (11$\bar{2}$2).

206.



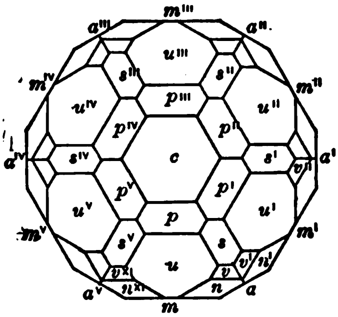
Connellite.

207.



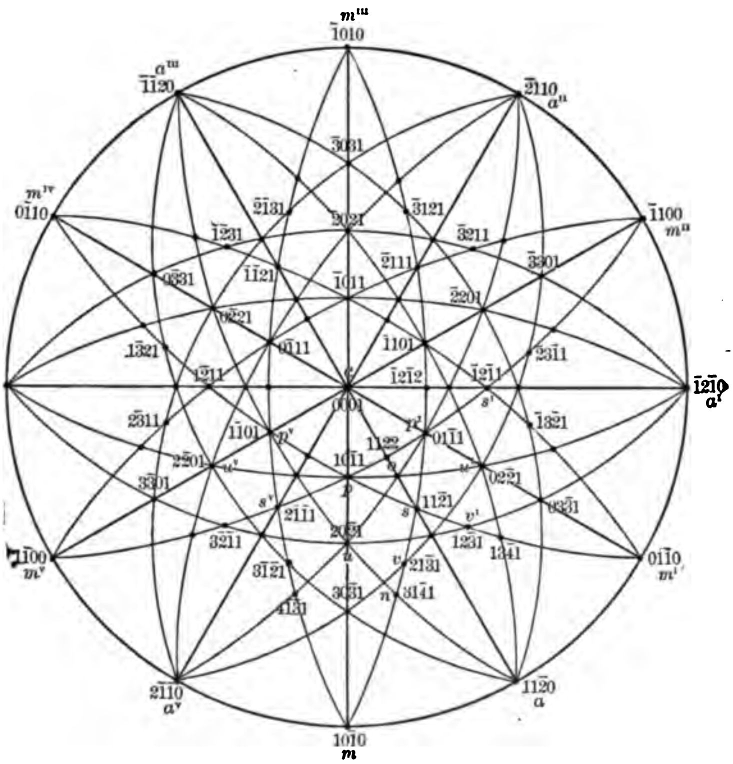
Beryl.

208.



Beryl.

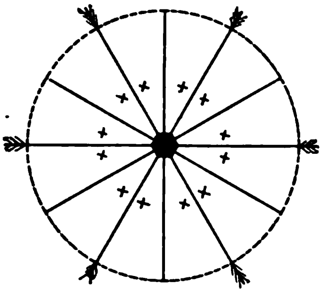
209



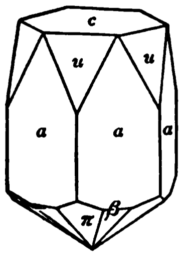
2. HEMIMORPHIC GROUP (14) IODYRITE TYPE.

126. Symmetry.—This group differs from the normal group only in having no transverse plane of principal symmetry and no horizontal axes of binary symmetry. It has, however, the same two sets of planes of symmetry meeting at angles of 30° in the vertical axis which is an axis of hexagonal symmetry. There is no center of symmetry. The symmetry is exhibited in the spherical projection, Fig. 210.

210.



211.



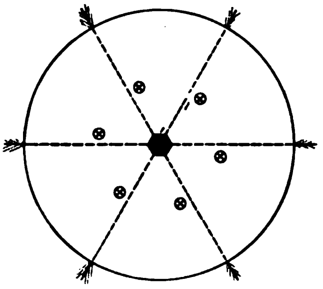
Iodyrite.

127 Forms. — The forms belonging to this group are the two basal planes, 0001 and 000$\bar{1}$, here distinct forms; the plus (upper) and minus (lower) pyramids of each of the three types; also the three prisms, which last do not differ geometrically from the prisms of the normal group. An example of this group is found in iodyrite, or silver iodide, Fig 211; here $u = (40\bar{4}1)$, $\pi = (40\bar{4}\bar{5})$, $\beta = (9{\cdot}9{\cdot}\bar{18}{\cdot}\bar{20})$. Greenockite and wurtzite, also zincite (Fig 50, p. 18) are classed here, but there is some reason for believing that these species belong, with tourmaline, to the corresponding group under the trigonal (rhombohedral) division.

3 PYRAMIDAL GROUP (15). APATITE TYPE.

128. Typical Forms and Symmetry.—This group is important because it includes the common species of the Apatite Group, apatite, pyromorphite, mimetite, vanadinite. The typical form is the hexagonal prism ($hk\bar{i}0$) and the hexagonal pyramid ($hk\bar{i}l$), each designated as of the *third order*. These forms are shown in Figs. 213 and 214. They and the other forms of the group have only one plane of symmetry, the plane of the horizontal axes, and also one axis of hexagonal symmetry (the vertical axis).

212.



The symmetry is exhibited in the spherical projection (Fig. 212). It is seen here, as in the figures of crystals given, that, like the pyramidal group under the tetragonal system, the faces of the general form ($hk\bar{i}l$) present are half those belonging to each sextant, and further that those above and below fall in same vertical zone.

129. Prism and Pyramid of the Third Order.—The prism of the third order (Fig. 213) has six like faces embraced under the general symbol ($hk\bar{i}0$), and the form is a regular hexagonal prism with angles of 60°, not to be distinguished geometrically, if alone, from the other hexagonal prisms; cf. Figs. 195, 196, p. 68 The six faces of the right-handed form ($21\bar{3}0$) have the symbols

$21\bar{3}0$, $\bar{1}3\bar{2}0$, $\bar{3}210$, $\bar{2}\bar{1}30$, $1\bar{3}20$, $3\bar{2}\bar{1}0$.

The faces of the complementary left-handed form have the symbols:

$12\bar{3}0$, $\bar{2}3\bar{1}0$, $\bar{3}120$, $\bar{1}\bar{2}30$, $2\bar{3}10$, $3\bar{1}\bar{2}0$.

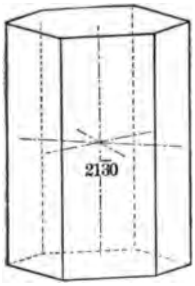
These two forms together embrace all the faces of the dihexagonal prism (Fig. 197).

The pyramid is also a regular hexagonal pyramid of the third order, and in its relations to the other hexagonal pyramids of the group (Figs. 199, 200) it is analogous to the square pyramid of the third order met with in the corresponding group of the tetragonal system (see Art. **98**). The faces of the right-handed form ($21\bar{3}3$) are:

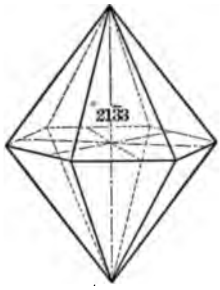
Above $21\bar{3}3$, $\bar{1}3\bar{2}3$, $\bar{3}213$, $\bar{2}\bar{1}33$, $1\bar{3}23$, $3\bar{2}\bar{1}3$.
Below $21\bar{3}\bar{3}$, $\bar{1}3\bar{2}\bar{3}$, $\bar{3}21\bar{3}$, $\bar{2}\bar{1}3\bar{3}$, $1\bar{3}2\bar{3}$, $3\bar{2}\bar{1}\bar{3}$.

There is also a complementary left-handed form, which with this embraces all the faces of the dihexagonal pyramid. The cross section of Fig. 215 shows in outline the position of the unit prism, and also that of the right-handed prism of the third order.

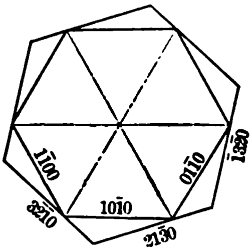
213.



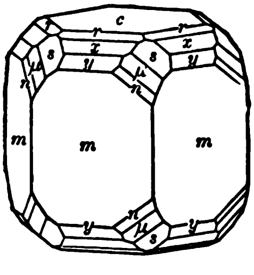
214.



215.

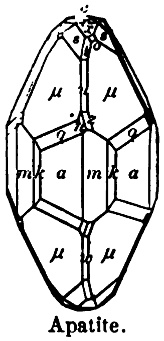


216.



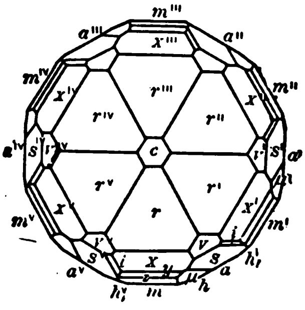
Apatite.

217.



Apatite.

218.



Apatite.

The prism and pyramid just described do not often appear on crystals as predominating forms, though this is sometimes the case; for example, Fig. 217 shows a crystal of apatite in which the prominent pyramid *μ* is a pyramid of the third order ($21\bar{3}1$). Commonly these faces are present modifying other fundamental forms, and their character is obvious from their position relatively, for example, to the unit prism *m* ($10\bar{1}0$).

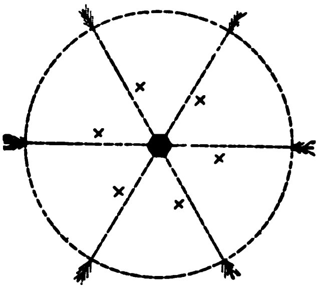
130. Other Forms.—The remaining forms of the group are geometrically like those of the normal group, viz., the base (0001); the unit prism $(10\bar{1}0)$; the diagonal prism $(11\bar{2}0)$; the unit pyramids $(h0\bar{h}l)$; and the diagonal pyramids $(h \cdot h \cdot 2\bar{h} \cdot l)$. That their molecular structure is the same is readily proved, for example by etching. In this way it was shown that pyromorphite and mimetite belong in the same group with apatite (Baumhauer), though crystals with the typical forms have not been observed.

131. Typical crystals of apatite are given in Figs. 216, 217, and 218 (a basal section). They show the third-order prisms *k* $(41\bar{5}0)$, *h* $(21\bar{3}0)$, h_1 $(12\bar{3}0)$, and the third order pyramids, right, μ $(21\bar{3}1)$, *n* $(31\bar{4}1)$, *q* $(43\bar{7}1)$, *o* $(31\bar{4}2)$, left, *i* $(12\bar{3}2)$; also the unit pyramids *r* $(10\bar{1}2)$, *x* $(10\bar{1}1)$, *y* $(20\bar{2}1)$, *z* $(30\bar{3}1)$; the diagonal pyramids *v* $(11\bar{2}2)$, *s* $(11\bar{2}1)$; finally, the prisms *m* $(10\bar{1}0)$, *a* $(11\bar{2}0)$, and the base *c* (0001).

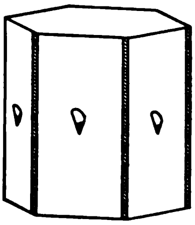
4. PYRAMIDAL-HEMIMORPHIC GROUP (16). NEPHELITE TYPE.

132. Symmetry.—A fourth group under the hexagonal system, the *pyramidal-hemimorphic group*, is like that just described, except that the forms are hemimorphic. The single horizontal plane of symmetry is absent, but the vertical axis is still an axis of hexagonal symmetry. This symmetry is shown in the spherical projection of Fig. 219. The typical form would be like the upper half of Fig. 214 of the pyramid of the third order. The species nephelite is shown by the character of the etching-figures (Fig. 220, Groth after Baumhauer) to belong here.

219.



220.

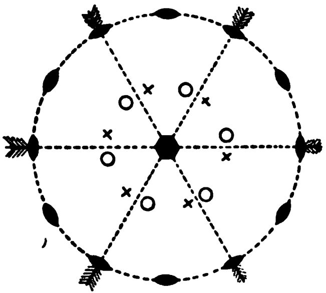


Nephelite.

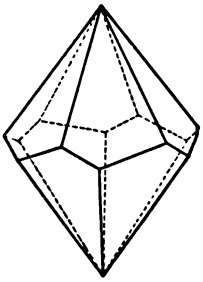
5. TRAPEZOHEDRAL GROUP (17).

133. Symmetry.—The last group of this division is the *trapezohedral group*. It has no plane of symmetry, but the vertical axis is an axis of hexagonal

221.



222.



symmetry, and there are, further, six horizontal axes of binary symmetry. There is no center of symmetry. The distribution of the faces of the typical form ($hk\bar{i}l$) is shown in the spherical projection (Fig. 221). The typical forms, the right and left hexagonal trapezohedrons (see Fig. 222), are enantiomorphous, and the few crystallized salts falling in this group show circular polarization. The symbols of the right form ($21\bar{3}3$) are as follows:

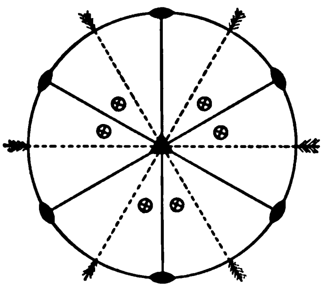
Above $21\bar{3}3$, $\bar{1}3\bar{2}3$, $\bar{3}213$, $\bar{2}\bar{1}33$, $1\bar{3}23$, $3\bar{2}\bar{1}3$.
Below $12\bar{3}\bar{3}$, $\bar{2}3\bar{1}\bar{3}$, $\bar{3}12\bar{3}$, $\bar{1}\bar{2}3\bar{3}$, $2\bar{3}1\bar{3}$, $3\bar{1}\bar{2}\bar{3}$.

B. Trigonal or Rhombohedral Division.

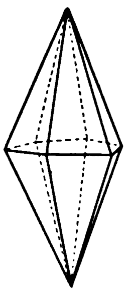
134. General Character.—As stated on p. 65, the groups of this division are characterized by a vertical axis of trigonal, or threefold, symmetry. There are seven groups here included of which the group of the Calcite Type is by far the most important.

135. Trigonotype Group.—The first group (18), that which has strictly the highest grade of symmetry, has no known representatives among crystals, natural or artificial. It has, besides the vertical axis of trigonal symmetry, three horizontal axes of binary symmetry. There are four planes of symmetry, one horizontal, and three others intersecting at angles of 60° in a vertical axis. The characteristic forms are the trigonal prism and pyramid and ditrigonal prism and pyramid. The symmetry is exhibited in Fig. 223. The typical form (Fig. 224) is a double ditrigonal pyramid with terminal edges alike in alternate sets of three each. This form may be compared to a scalenohedron twinned about the vertical axis.

223.



224.

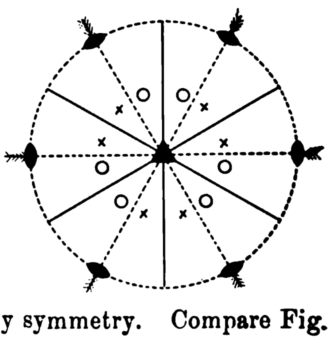


2. RHOMBOHEDRAL GROUP (19). CALCITE TYPE.

136. Typical Forms and Symmetry.—The typical forms of the *rhombohedral group* are the rhombohedron (Fig. 226) and the scalenohedron (Fig. 242). These forms, with the spherical projection, Figs. 225 and 252, illustrate the symmetry characteristic of the group. By comparing Fig. 252 with Fig. 209, p. 70, it will be seen that all the faces in half the sectants are present. This group is hence analogous to the tetrahedral group of the isometric system, and the sphenoidal group of the tetragonal system.

In this group there are three planes of symmetry only; these are diagonal to the crystallographic axes and intersect at angles of 60° in the vertical crystallographic axis. This axis is with these forms an axis of trigonal symmetry; there are, further, three horizontal axes of binary symmetry. Compare Fig. 225, also Fig. 226 *et seq.*

225.



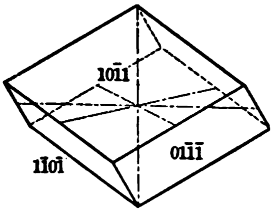
137. Rhombohedron.—Geometrically described, the *rhombohedron* is a solid bounded by six like faces, each a rhomb. It has six like lateral edges forming a zigzag line about the crystal, and six like terminal edges, three above and three in alternate position below. The vertical axis joins the two trihedral solid angles, and the lateral axes join the middle points of the opposite sides, as shown in Fig. 226.

The general symbol of the rhombohedron is $(h0\bar{h}l)$, and the successive faces of the unit form $(10\bar{1}1)$ have the symbols:

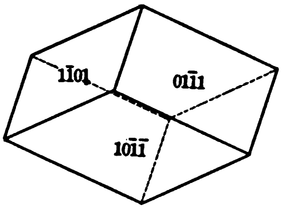
Above, $10\bar{1}1$, $\bar{1}101$, $0\bar{1}11$; below, $01\bar{1}\bar{1}$, $\bar{1}01\bar{1}$, $1\bar{1}0\bar{1}$.

The geometrical shape of the rhombohedron varies widely as the angles change, and consequently the relative length of the vertical axis $\dot{c}$ (expressed in terms of the lateral axes, $a = 1$). As the vertical axis diminishes, the rhombohedrons become more and more obtuse or flattened; and as it increases they become more and more acute. A cube placed with an octahedral axis vertical is obviously the limiting case between the obtuse and acute forms where the interfacial angle is 90°. In Fig. 226 of calcite the normal rhombohedral angle is 74° 55′ and $\dot{c} = 0{\cdot}854$, while for Fig. 228 of hematite this angle is 94° and $\dot{c} = 1{\cdot}366$. Further, Figs. 229–234 show other rhombohedrons of calcite, namely, *e* $(01\bar{1}2)$, *φ* $(05\bar{5}4)$, *f* $(02\bar{2}1)$, *M* $(40\bar{4}1)$, and *ν* $(13\cdot0\cdot\overline{13}\cdot1)$, *ρ* $(16\cdot0\cdot\overline{16}\cdot1)$, here the vertical axes are in the ratio of $\frac{1}{2}$, $\frac{5}{4}$, 2, 4, 13, 16, to that of the fundamental (cleavage) rhombohedron of Fig. 226, whose angle determines the value of $\dot{c}$.

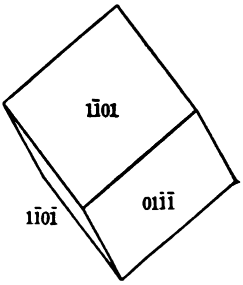
226.



227.



228.



138. Plus and Minus Rhombohedrons.—To every plus rhombohedron there may be an inverse and complementary form, identical geometrically, but bounded by faces falling in the alternate sectants. Thus the minus form of the unit rhombohedron $(01\bar{1}1)$ shown in Fig. 227 has the faces:

Above, $01\bar{1}1$, $\bar{1}011$, $1\bar{1}01$; below, $\bar{1}10\bar{1}$, $0\bar{1}1\bar{1}$, $10\bar{1}\bar{1}$.

The position of these in the spherical projection (Fig. 252) should be carefully studied; see also Fig. 262. Of the figures already referred to, Figs. 226, 228, 232, 233 are plus, and Figs. 227, 229, 230, 231 minus, rhombohedrons; Fig. 234 shows both forms.

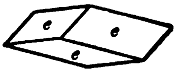
It will be seen that the two complementary plus and minus rhombohedrons of given axial length, that is, of given angle, *e.g.*, $10\bar{1}1$ $(+R)$ and $0\bar{1}11$ $(-R)$, together embrace all the like faces of the double six-sided pyramid. When these two rhombohedrons are equally developed the form is geometrically identical with this pyramid. This is illustrated by Fig. 237 of gmelinite *r* $(10\bar{1}1)$, *ρ* $(01\bar{1}1)$ and by Figs. 266, 267, p. 83, of quartz, *r* $(10\bar{1}1)$, *z* $(01\bar{1}1)$.*

---

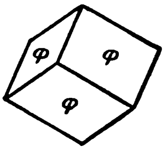
* Quartz serves as a convenient illustration in this case, none the less so notwithstanding the fact that it belongs to the trapezohedral group of this division.

In each case the form, which is geometrically an hexagonal pyramid (in Fig. 237 with c and m), is in fact a combination of the two unit rhombohedrons, plus and minus. Commonly a difference in size between the two forms may be observed, as in Figs. 236 and 268, where the form taken as the plus rhombohedron predominates. But even if this distinction cannot be established, the two rhombohedrons can always be distinguished by etching, or, as in the case of quartz, by pyro-electrical phenomena.

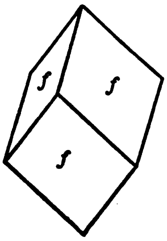
229.



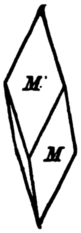
230.



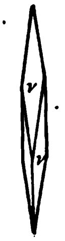
231.



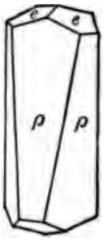
232.



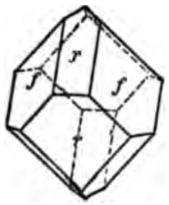
233.



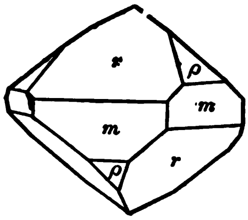
234.



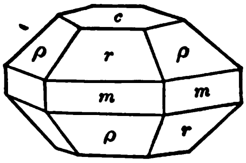
235.



236.



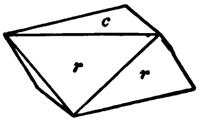
237.



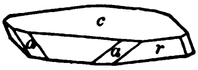
Figs. 229–235, Calcite. Figs. 236, 237, Gmelinite.

139. Of the two series, or zones, of rhombohedrons the faces of the *plus rhombohedrons* replace the edges between the base (0001) and the unit prism $(10\bar{1}0)$. Also the faces of the *minus rhombohedrons* replace the alternate edges of the same forms, that is, the edges between (0001) and $(01\bar{1}0)$, (compare Figs. 236, 237, etc.). Fig. 238 shows the rhombohedron in combination with the base; Fig. 239 the same with the prism a $(11\bar{2}0)$. When the angle between the two forms happens to approximate to 70° 32′ the crystal simulates the aspect of a regular octahedron. This is illustrated by Fig. 240; here $co = 69^\circ 42'$,

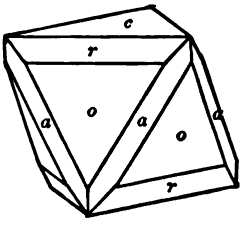
238.



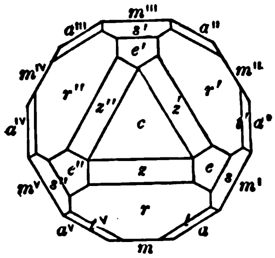
239.



240.



241.



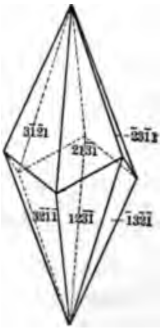
Figs 238, 239, Hematite. Coquimbite. Eudialyte.

also $oo = 71° 22'$, and the crystal resembles closely an octahedron with truncated edges (cf. Fig. 77, p. 36).

140. There is a very simple relation between the plus and minus rhombohedrons which it is important to remember. The form of one series which truncates the terminal edges of a given form of the other has half the length of the vertical axis, and this ratio is expressed in the values of the indices of the two forms. Thus $(01\bar{1}2)$, or $-\frac{1}{2}$R, truncates the terminal edges of the plus unit rhombohedron $(10\bar{1}1)$, or R; $(10\bar{1}4)$, or $+\frac{1}{4}$R, truncates the terminal edges of $(01\bar{1}2)$, or $-\frac{1}{2}$R, $10\bar{1}5$ of $(20\bar{2}5)$. Again $(10\bar{1}1)$, or $+$ R, truncates the edges of $(02\bar{2}1)$, or $-$ 2R; $(40\bar{4}1)$, or $+$ 4R, of $02\bar{2}1$, or $-$ 2R, etc. This is illustrated by Fig. 235 with the forms *r* $(10\bar{1}1)$ and *f* $(02\bar{2}1)$. Also in Fig. 241 a basal projection, *z* $(10\bar{1}4)$ truncates the edges of *e* $(01\bar{1}2)$, *e* $(01\bar{1}2)$ of *r* $(10\bar{1}1)$; *r* $(1\bar{1}01)$ of *s* $(02\bar{2}1)$.

141. Scalenohedron.—The *scalenohedron*, shown in Fig. 242, is the general form for this group corresponding to the symbol $hk\bar{i}l$. It is a solid, bounded by twelve faces, each a scalene triangle. It has roughly the shape of a double six-sided pyramid, but there are two sets of terminal edges, one more obtuse than the other, and the lateral edges form a zigzag edge around like that of the rhombohedron. Like the rhombohedrons, the scalenohedrons may be either plus or minus according as to whether the faces are symmetrical to the zone-circle $10\bar{1}0$, 0001, or to $01\bar{1}0$, 0001. The former plus forms correspond in position to the plus rhombohedrons and conversely.

242.



Scalenohedron.

The plus scalenohedron $(21\bar{3}1)$, Fig. 242) has the following symbols for the several faces:

Above $21\bar{3}1$, $\bar{2}3\bar{1}1$, $\bar{3}211$, $\bar{1}\bar{2}31$, $1\bar{3}21$, $3\bar{1}\bar{2}1$.
Below $12\bar{3}\bar{1}$, $\bar{1}3\bar{2}\bar{1}$, $\bar{3}12\bar{1}$, $\bar{2}\bar{1}3\bar{1}$, $2\bar{3}4\bar{1}$, $3\bar{2}\bar{1}\bar{1}$.

For the complementary minus scalenohedron $(12\bar{3}1)$ the symbols of the faces are:

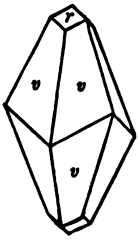
Above $12\bar{3}1$, $\bar{1}3\bar{2}1$, $\bar{3}121$, $\bar{2}\bar{1}31$, $2\bar{3}11$, $3\bar{2}\bar{1}1$.
Below $\bar{2}3\bar{1}\bar{1}$, $\bar{3}21\bar{1}$, $\bar{1}\bar{2}3\bar{1}$, $1\bar{3}2\bar{1}$, $3\bar{1}\bar{2}\bar{1}$, $21\bar{3}\bar{1}$.

142. Relation of Scalenohedrons to Rhombohedrons.—It was noted above that the scalenohedron in general has a series of zigzag lateral edges like the rhombohedron. It is obvious, further, that for every rhombohedron there will be a series or zone of scalenohedrons having the *same* lateral edges. This is shown in Fig. 245, where the scalenohedron *v* $(21\bar{3}1)$ bevels the lateral edges of the fundamental rhombohedron *r* $(10\bar{1}1)$; the same would be true of the scalenohedron $(32\bar{5}1)$, etc. Further, in Fig. 246, the minus scalenohedron *x* $(13\bar{4}1)$ bevels the lateral edges of the minus rhombohedron *f* $(02\bar{2}1)$. The relation of the indices which must exist in these cases may be shown to be, for example, for the rhombohedron *r* $(10\bar{1}1)$, $h = k + l$; again for *f* $(02\bar{2}1)$, $h + 2l = k$, etc. See also the projection. Fig. 252.

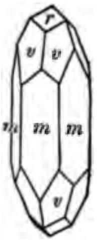
Further, the position of the scalenohedron may be defined with reference to its parent rhombohedron. For example, in Fig. 245 the scalenohedron *v* $(21\bar{3}1)$ has three times the vertical axis of the unit rhombohedron *r* $(10\bar{1}1)$. Again in Fig 246 *x* $(13\bar{4}1)$ has twice the vertical axis of *f* $(02\bar{2}1)$. Hence the system of symbols devised by Naumann to express this relation, written in general mRn or (in Dana's System m^n), where the n expresses the multiple value of the vertical axis corresponding to the rhombohedron mR. The symbol of *v* is on this system R3 or 1^3, and of $x - 2R_2$, or $- 2^2$. If mPn is the symbol of a scalenohedron on the hexagonal type and m_0Rn_0 that referred in this way, it may be shown that

$$m_0 = \frac{m(2-n)}{n}, \quad n_0 = \frac{n}{2-n}. \quad \text{Also } m = m_0 n_0, \quad n = \frac{2n}{n_0 + 1}.$$

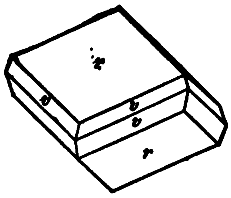
243.



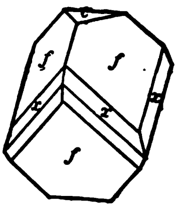
244.



245.

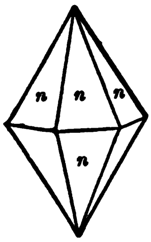


246.

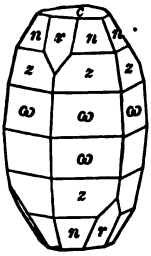


Figs. 243-246, Calcite.

247.

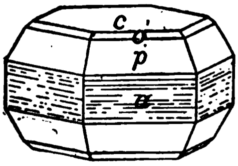


248.

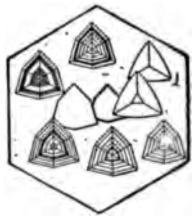


Figs. 247, 248, Corundum.

249.



250.

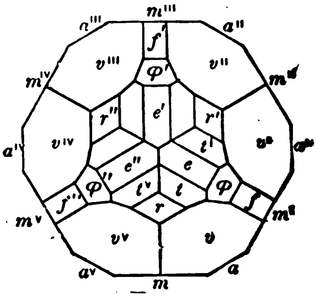


Figs. 249, 250, Spangolite.*

143. Other Forms.—The remaining forms of the normal group of the rhombohedral division are geometrically like those of the corresponding group of the hexagonal system—viz., the base *c* (0001); the prisms *m* (10$\bar{1}$0), *a* (11$\bar{2}$0), (*hk$\bar{i}$*0); also the diagonal pyramids, as (11$\bar{2}$1). Some of these forms are shown in the accompanying figures. For further illustrations reference may be made to typical rhombohedral species, as calcite, hematite, etc.

With respect to the diagonal pyramid, it is interesting to note that if it occurs alone (as in Fig. 247, *n* = 22$\bar{4}$3) it is impossible to say, on geometrical grounds, whether it has the trigonal symmetry of the rhombohedral type or the hexagonal symmetry of the hexagonal type. In the latter case, the form might be made a unit pyramid by exchanging the axial and diagonal planes of symmetry. The true symmetry, however, is often indicated, as with corundum, by the occurrence on other crystals of rhombohedral faces, as *r* (10$\bar{1}$1) in Fig. 248 (here *z* = 22$\bar{4}$1, *ω* = 14·14·$\bar{28}$·3). Even if these are absent (Fig. 249), the etching-figures (Fig. 250) will often serve to reveal the true trigonal molecular symmetry; here *o* = (11$\bar{2}$4), *p* = (11$\bar{2}$2).

251.

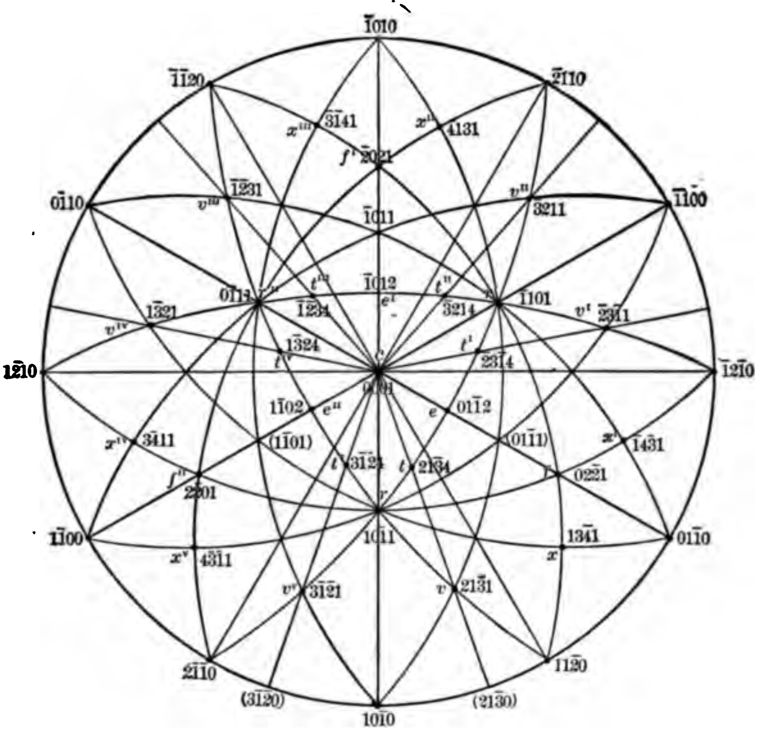


144. A basal projection of a somewhat complex crystal of calcite is given in Fig. 251, and a spherical projection for the same species in Fig. 252; both show well the symmetry in the distribution of the faces. Here the forms are: prisms, *a* (11$\bar{2}$0), *m* (10$\bar{1}$0); rhombohedrons, plus, *r* (10$\bar{1}$1), minus *e* (01$\bar{1}$2), *φ* (05$\bar{5}$4), *f* (02$\bar{2}$1); scalenohedrons, plus, *v* (21$\bar{3}$1), *t* (21$\bar{3}$4), minus, *x* (13$\bar{4}$1).

---

* Spangolite belongs properly to the next (hemimorphic) group, but this fact does not destroy the value of the illustration.

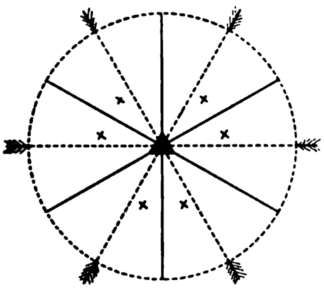
252.



3. RHOMBOHEDRAL-HEMIMORPHIC GROUP (20). TOURMALINE TYPE.

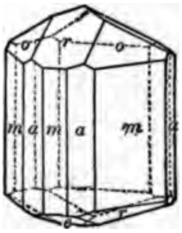
145. Symmetry.—A number of prominent rhombohedral species, as tourmaline, pyrargyrite, proustite, belong to a hemimorphic group under this division. For them the symmetry in the grouping of the faces differs at the two extremities of the vertical axis. The forms have the three diagonal planes of symmetry meeting at angles of 60° in the vertical axis, which is an axis of trigonal symmetry. There are, however, no horizontal axes of symmetry, as in the rhombohedral group, and there is no center of symmetry. Cf. Fig. 253.

253.

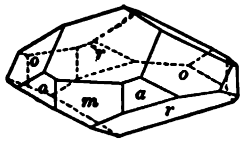


146. Typical Forms. — In this group the basal planes (0001) and (000$\bar{1}$) are distinct forms. The other characteristic forms are the two trigonal prisms *m* (10$\bar{1}$0) and *m*$_{,}$ (01$\bar{1}$0) of the unit series; also the four trigonal unit pyramids, corresponding respectively to the three upper and three lower faces of a plus rhombohedron, and the three upper and three lower faces of the minus rhombohedron; also the hemimorphic diagonal hexagonal pyramid; finally, the four ditrigonal pyramids, corresponding to the upper and lower faces respectively of the plus and minus scalenohedrons. Figs. 254–257 illustrate these forms. Fig. 256 is a basal section with $r_,$ $(01\bar{1}\bar{1})$ and $e_,$ $(10\bar{1}\bar{2})$ below.

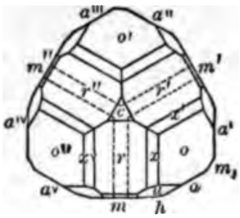
254.



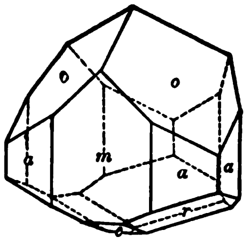
255.



256.



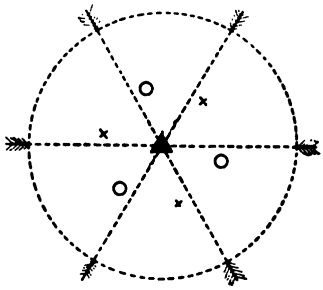
257.



Figs. 254–257, Tourmaline, *m* $(10\bar{1}0)$, *m*, $(01\bar{1}0)$, *a* $(11\bar{2}0)$, *h* $(41\bar{5}0)$, *r* $(10\bar{1}1)$, *o* $(02\bar{2}1)$, *e*, $(10\bar{1}\bar{2})$, *u* $(32\bar{5}1)$, *x* $(12\bar{3}2)$.

4. TRI-RHOMBOHEDRAL GROUP (21). PHENACITE TYPE.

258.



147. Symmetry.—This group, illustrated by the species dioptase, phenacite, willemite, dolomite, ilmenite, etc., is an important one. It is characterized by the absence of all planes of symmetry, but the vertical axis is still an axis of trigonal symmetry, and there is a center of symmetry. Cf. Fig. 258.

148. Typical Forms.—The distinctive forms of the group are the rhombohedron of the second order and the hexagonal prism and rhombohedron, each of the third order. The group is thus characterized by three distinct rhombohedrons (each + and −), and hence the name given to it.

The complementary plus and minus rhombohedrons of the *second order* together embrace all the faces of the diagonal pyramid of the normal group. For example, in a given case the faces for the plus and minus forms are:

Plus (above) $11\bar{2}2$, $\bar{2}112$, $1\bar{2}12$; (below) $\bar{1}2\bar{1}\bar{2}$, $\bar{1}\bar{1}2\bar{2}$, $2\bar{1}\bar{1}\bar{2}$,
Minus (above) $\bar{1}2\bar{1}2$, $\bar{1}\bar{1}22$, $2\bar{1}\bar{1}2$; (below) $\bar{2}11\bar{2}$, $1\bar{2}1\bar{2}$, $11\bar{2}\bar{2}$.

The rhombohedron of the *third order* has the general symbol $(hk\bar{i}l)$, and the symbols of the six like faces of the plus right-handed form $(21\bar{3}1)$ are:

Above $21\bar{3}1$, $\bar{3}211$, $1\bar{3}21$; below $\bar{1}3\bar{2}\bar{1}$, $\bar{2}\bar{1}3\bar{1}$, $3\bar{2}\bar{1}\bar{1}$.

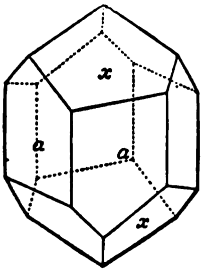
There are three other complementary rhombohedrons, distinguished respectively as plus left-handed $(3\bar{1}\bar{2}1)$, minus right-handed $(\bar{1}3\bar{2}1)$, and minus left-handed $(12\bar{3}1)$. These four sets of faces make up the twenty-four like faces of the dihexagonal pyramid of Fig. 201. In Fig. 259 (drawn in the reverse position) the minus right-handed form $(\bar{1}3\bar{2}2)$ is shown.

The complementary right and left hexagonal prisms of the third order embrace all the faces of the dihexagonal prism (Fig. 197). The faces in a given case $(21\bar{3}0)$ have the symbols:

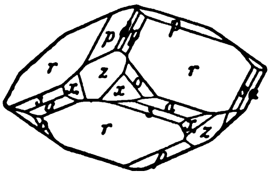
Right $21\bar{3}0$, $\bar{1}3\bar{2}0$, $\bar{3}210$, $\bar{2}\bar{1}30$, $1\bar{3}20$, $3\bar{2}\bar{1}0$,
Left $12\bar{3}0$, $\bar{2}3\bar{1}0$, $\bar{3}120$, $\bar{1}\bar{2}30$, $2\bar{3}10$, $3\bar{1}\bar{2}0$.

149. The remaining forms are geometrically like those of the rhombohedral group, viz.: Base *c* (0001); unit prism *m* $(10\bar{1}0)$; diagonal prism *a* $(11\bar{2}0)$; rhombohedrons of the first order, as $(10\bar{1}1)$ and $(01\bar{1}1)$, etc.

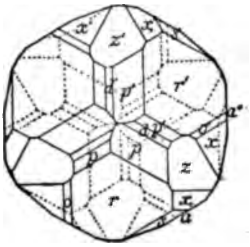
259.



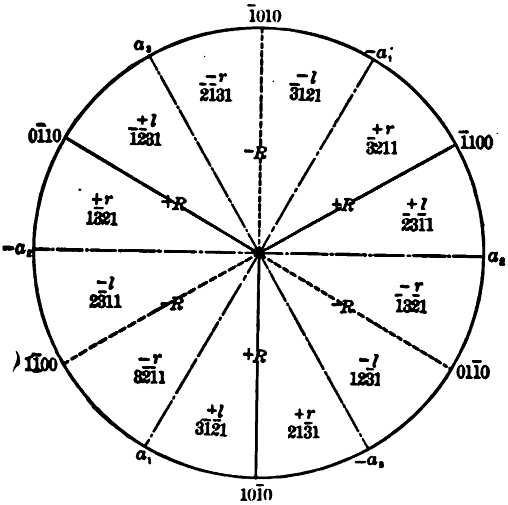
260.



261.



262.



150. The forms of this group are best illustrated by the crystals of the species phenacite, with which the minus right rhombohedron *x* $(\bar{1}3\bar{2}2)$ is not infrequently the predominating form, as in Fig. 259. The true position of this rhombohedron is shown by its relation to the prisms *m* ($10\bar{1}0$) and *a* ($11\bar{2}0$). A more complex crystal of the same species* is given in Fig. 260, and a basal projection (in normal position) is shown in Fig. 261. The faces present are: rhombohedrons, first order, plus, *r* ($10\bar{1}1$), minus, *z* ($01\bar{1}1$), *d* ($01\bar{1}2$); second order, right, *p* ($11\bar{2}3$), left, $p_{,}$ ($2\bar{1}\bar{1}3$), $o_{,}$ ($4\bar{2}\bar{2}3$); third order, plus right, *s* ($21\bar{3}1$), minus left, $x_{,}$ ($12\bar{3}2$), minus right, *x* ($\bar{1}3\bar{2}2$).

In order to make clearer the relation of the faces of the different types of forms under this group, Fig. 262 is added. Here the zones of the plus and minus rhombohedrons of the first order are indicated, also the plus and minus sectants corresponding to each.

The following scheme may also be helpful in connection with Fig. 262. It shows the distribution of the faces of the four rhombohedrons of the third order (+ *r*, + *l*, − *r*, − *l*) relatively to the faces of the unit hexagonal prism ($10\bar{1}0$).

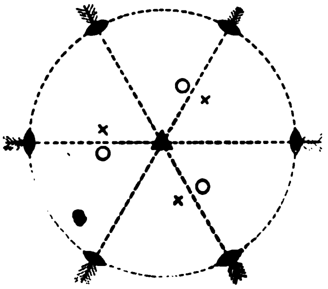
PHENACITE TYPE.

+ *l* + *r*	− *l* − *r*	+ *l* + *r*	− *l* − *r*	+ *l* + *r*	− *l* − *r*
$3\bar{1}\bar{2}1$ $21\bar{3}1$	$12\bar{3}1$ $\bar{1}3\bar{2}1$	$\bar{2}3\bar{1}1$ $\bar{3}211$	$\bar{3}121$ $\bar{2}\bar{1}31$	$\bar{1}\bar{2}31$ $1\bar{3}21$	$2\bar{3}11$ $3\bar{2}\bar{1}1$
$10\bar{1}0$	$01\bar{1}0$	$\bar{1}100$	$\bar{1}010$	0110	$1\bar{1}00$
− *l* − *r*	+ *l* + *r*	− *l* − *r*	+ *l* + *r*	− *l* − *r*	+ *l* + *r*
$3\bar{1}\bar{2}\bar{1}$ $21\bar{3}\bar{1}$	$12\bar{3}\bar{1}$ $\bar{1}3\bar{2}\bar{1}$	$\bar{2}3\bar{1}\bar{1}$ $\bar{3}21\bar{1}$	$\bar{3}12\bar{1}$ $\bar{2}\bar{1}3\bar{1}$	$\bar{1}\bar{2}3\bar{1}$ $1\bar{3}2\bar{1}$	$2\bar{3}1\bar{1}$ $3\bar{2}\bar{1}\bar{1}$

5. TRAPEZOHEDRAL GROUP (22). QUARTZ TYPE.

151. Symmetry.—This group includes, among minerals, the species quartz and cinnabar. The forms have no plane of symmetry and no center of symmetry; the vertical axis is, however, an axis of trigonal symmetry, and there are also three horizontal axes of binary symmetry, coinciding in direction with the crystallographic axes; cf. Fig. 263.

263.



152. Typical Forms. — The characteristic form of the group is the trigonal trapezohedron shown in Fig. 264. This is the general form corresponding to the symbol ($hk\bar{i}l$), the faces being distributed as indicated in the accompanying spherical projection (Fig. 263). There are four such trapezohedrons, two plus, called respectively right-handed (Fig. 264) and left-handed (Fig. 265), and two similar minus forms, also right- and left-handed (see the scheme given in Art. **154**). It is obvious that the two forms of Figs. 264, 265 are enantiomorphous, and circular polarization is a striking character of the species belonging to the group as elsewhere discussed.

The symbols of the six faces belonging to each of these will be evident on consulting Figs. 263 and 209, p. 70. The complementary plus forms (*r* and *l*) of a given symbol include the twelve faces of a plus scalenohedron, while the faces of all four include the twenty-four faces of the dihexagonal pyramid.

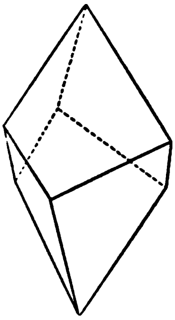
---

* Drawn with the zone of minus rhombohedrons in front to better show the modifying faces. Fig. 259 is similar.

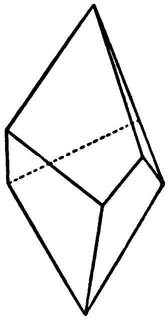
Corresponding to these trapezohedrons there are two *ditrigonal prisms*, respectively right- and left-handed, as $(21\bar{3}0)$ and $(3\bar{1}\bar{2}0)$.

The remaining characteristic forms are the right- and left-handed *trigonal prism* *a* $(11\bar{2}0)$ and *a* $(2\bar{1}\bar{1}0)$; also the right- and left-handed *trigonal pyramid*, as $(11\bar{2}2)$ and $(2\bar{1}\bar{1}2)$. They include respectively the faces of the hexagonal prism of the second order $(11\bar{2}0)$ and those of the corresponding pyramid $(11\bar{2}2)$; these are shown in Figs. 196 and 200.

264.

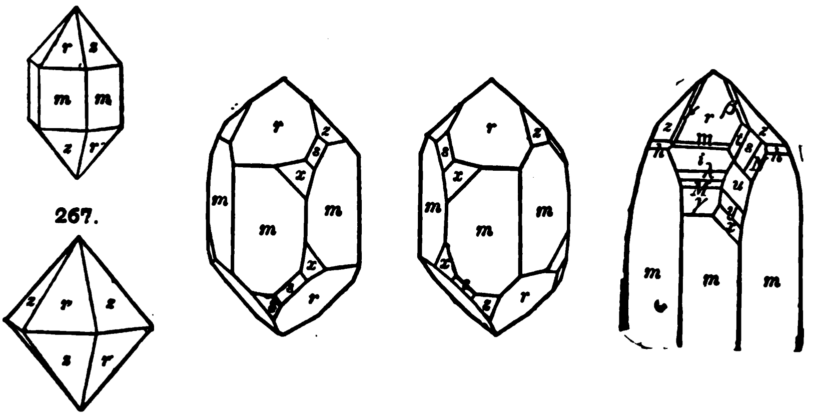


265.



153. Other Forms.—The other forms of the group are geometrically like those of the normal group. They are the base *c* (0001), the hexagonal unit prism *m* $(10\bar{1}0)$, and the plus and minus rhombohedrons as $(10\bar{1}1)$ and $(01\bar{1}1)$. These cannot be distinguished geometrically from the normal forms.

154. Illustrations.—The forms of this group are best shown in the species quartz. As already remarked (p. 75), simple crystals often appear to be of normal hexagonal symmetry, the rhombohedrons *r* $(10\bar{1}1)$ and *z* $(01\bar{1}1)$ being equally developed (Figs. 266, 267). In many cases, however, a difference in molecular character between them can be observed, and more commonly one rhombohedron, *r* $(10\bar{1}1)$, predominates; the distinction can always be made out by etching. Some crystals, like Fig. 268, show as modifying faces the *right* trigonal pyramid *s* $(11\bar{2}1)$, with a *right plus* trapezohedron, as *x* $(51\bar{6}1)$. Such crystals are called right-handed and rotate the plane of polarization of light transmitted in the direction of the vertical axis to the right. A crystal, like Fig. 269, with the *left* trigonal pyramid *s* (2 1) and one or more *left* trapezohedrons, as *x* $(6\bar{1}\bar{5}1)$, is called left-handed, and as regards light has the opposite


266. 268. 269. 270. 267.

Figs. 266–270, Quartz.

character to that of Fig. 268. Fig. 270 shows a more complex right-handed crystal with several plus and minus rhombohedrons, several plus right trapezohedrons and the minus left trapezohedron, *N*.

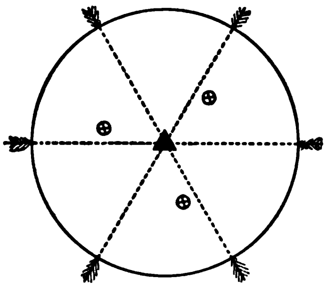
The following scheme shows the distribution of the faces of the four trapezohedrons ($+r$, $+l$, $-r$, $-l$) relatively to the faces of the unit hexagonal prism ($10\bar{1}0$); it is to be compared with the corresponding scheme, given in Art. **150**, of crystals of the phenacite type. In the case of the minus forms some authors prefer to make the faces $21\bar{3}\bar{1}$, $12\bar{3}1$, etc., *right*, and $3\bar{1}\bar{2}\bar{1}$, $\bar{1}3\bar{2}1$, etc., *left*.

QUARTZ TYPE.

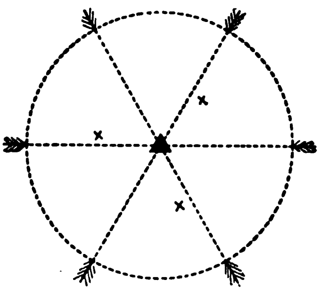
$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$
$3\bar{1}\bar{2}1$ $21\bar{3}1$	$12\bar{3}1$ $\bar{1}3\bar{2}1$	$\bar{2}3\bar{1}1$ $\bar{3}211$	$\bar{3}121$ $\bar{2}\bar{1}31$	$\bar{1}\bar{2}31$ $1\bar{3}21$	$2\bar{3}11$ $3\bar{2}\bar{1}1$
$10\bar{1}0$	$01\bar{1}0$	1100	$\bar{1}010$	$0\bar{1}10$	$1\bar{1}00$
$-r$ $-l$	$+r$ $+l$	$-r$ $-l$	$+r$ $+l$	$-r$ $-l$	$+r$ $+l$
$3\bar{1}\bar{2}\bar{1}$ $21\bar{3}\bar{1}$	$12\bar{3}\bar{1}$ $\bar{1}3\bar{2}\bar{1}$	$\bar{2}31\bar{1}$ $\bar{3}21\bar{1}$	$\bar{3}12\bar{1}$ $\bar{2}\bar{1}3\bar{1}$	$\bar{1}\bar{2}3\bar{1}$ $1\bar{3}2\bar{1}$	$2\bar{3}1\bar{1}$ $3\bar{2}\bar{1}\bar{1}$

155. Other Groups.—The next group (23) has one plane of symmetry—that of the horizontal axes, and one axis of trigonal symmetry—the vertical axis. There is no center of symmetry. Its characteristic forms are the three types of trigonal prisms and the three corresponding types of trigonal pyramids. Cf. Fig. 271.

271.



272.



The last group (24) has no plane of symmetry and no center of symmetry, but the vertical axis is an axis of trigonal symmetry. The forms are all hemimorphic, the prisms trigonal prisms, and the pyramids hemimorphic trigonal pyramids. Cf. Fig. 272. Neither of these groups is known to be represented among crystals.

MATHEMATICAL RELATIONS OF THE HEXAGONAL SYSTEM.

156. Choice of Axis.—The position of the vertical crystallographic axis is fixed in all the groups of this system since it coincides with the axis of hexagonal symmetry in the hexagonal division and that of trigonal symmetry in the rhombohedral division. The three lateral axes are also fixed in direction except in the normal group and the subordinate hemimorphic group of the hexagonal division; in these there is a choice of two positions according to which of the two sets of vertical planes of symmetry is taken as the axial set.

157. Axial and Angular Elements.—The axial element is the length of the vertical axis, $\dot{c}$, in terms of a lateral axis, a; in other words, the axial ratio of $a : \dot{c}$. A single measured angle (in any zone but the prismatic) may be taken as the fundamental angle from which the axial ratio can be obtained.

The angular element is usually taken as the angle between the base *c* (0001) and the unit pyramid ($10\bar{1}1$), that is, $0001 \wedge 10\bar{1}1$.

The relation between this angle and the axis $\dot{c}$ is given by the formula

$$\tan (0001 \wedge 10\bar{1}1) \times \frac{1}{2}\sqrt{3} = \dot{c}.$$

The vertical axis is also easily obtained from the unit diagonal pyramid, since

$$\tan (0001 \wedge 11\bar{2}2) = \dot{c}.$$

These relations become general by writing them as follows:

$$\tan (0001 \wedge h0\bar{h}l) \times \frac{1}{2}\sqrt{3} = \frac{h}{l} \times \dot{c};$$

$$\tan (0001 \wedge h \cdot h \cdot 2\bar{h}l) \qquad = \frac{2h}{l} \times \dot{c}.$$

In general it is easy to obtain any required angle between the poles of two faces on the spherical projection either by the use of the tangent (or cotangent) relation, or by the solution of spherical triangles, or by the application of both methods. In practice most of the triangles used in calculation are right-angled.

158. Tangent and Cotangent Relations.—The tangent relation holds good in any zone from *c* (0001) to a face in the prismatic zone. For example:

$$\frac{\tan (0001 \wedge h0\bar{h}l)}{\tan (0001 \wedge 10\bar{1}1)} = \frac{h}{l}; \quad \frac{\tan (0001 \wedge h \cdot h \cdot 2\bar{h} \cdot l)}{\tan (0001 \wedge 1122)} = \frac{2h}{l}.$$

In the prismatic zone, the cotangent formula takes a simplified form; for example, for a dihexagonal prism, $hk\bar{i}0$, as ($21\bar{3}0$):

$$\cot (10\bar{1}0 \wedge hk\bar{i}0) = \frac{2h+k}{k}\sqrt{\frac{1}{3}};$$

$$\cot (11\bar{2}0 \wedge hk\bar{i}0) = \frac{h+k}{h-k}\sqrt{3}.$$

The sum of the angles ($1010 \wedge hk\bar{i}0$) and ($11\bar{2}0 \wedge hk\bar{i}0$) is equal to 30°.

Further, the last equations can be written in a more general form, applying to any pyramid ($hk\bar{i}l$) in a zone, first between $10\bar{1}0$ and a face in the zone 0001 to $01\bar{1}0$, where the angle between $10\bar{1}0$ and this face is known; or again, for the same pyramid, in a zone between $11\bar{2}0$ and a face in the zone 0001 to $10\bar{1}0$, the angle between $11\bar{2}0$ and this face being given. For example (cf. Fig. 209, p. 70), if the first-mentioned zone is $10\bar{1}0 \cdot hk\bar{i}l \cdot 01\bar{1}1$ and the second is $11\bar{2}0 \cdot hk\bar{i}l \cdot 10\bar{1}1$, then

$$\cot (10\bar{1}0 \wedge hk\bar{i}l) = \cot (10\bar{1}0 \wedge 01\bar{1}1) \,.\, \frac{2h+k}{k},$$

and

$$\cot (11\bar{2}0 \wedge hk\bar{i}l) = \cot (11\bar{2}0 \wedge 10\bar{1}1) \,.\, \frac{h+k}{h-k}.$$

Also similarly for other zones,

$$\cot (10\bar{1}0 \wedge hk\bar{i}l) = \cot (10\bar{1}0 \wedge 02\bar{2}1) \,.\, \frac{2h+k}{k}, \text{ etc.}$$

$$\cot (11\bar{2}0 \wedge hk\bar{i}l) = \cot (10\bar{1}0 \wedge 20\bar{2}1) : \frac{h+k}{h-k}, \text{ etc.}$$

159. Other Angular Relations.—The following simple relations are of frequent use:
(1) For a *unit hexagonal pyramid*

$$\tan \tfrac{1}{2}(10\bar{1}1 \wedge 01\bar{1}1) = \sin \xi\sqrt{\tfrac{1}{3}}, \text{ where } \tan \xi = \dot{c},$$

and in general

$$\tan \tfrac{1}{2}(h0\bar{h}l \wedge 0h\bar{h}l) = \sin \xi_{,}\sqrt{\tfrac{1}{3}}, \text{ where } \tan \xi_{,} = \frac{h}{l}\dot{c}.$$

(2) For a *diagonal pyramid*, as $(11\bar{2}2)$,

$$2 \sin \tfrac{1}{2}(11\bar{2}2 \wedge \bar{1}2\bar{1}2) = \sin \xi, \quad \text{and} \quad \tan \xi = \dot{c}.$$

(3) For a *rhombohedron*

$$\sin \tfrac{1}{2}(10\bar{1}1 \wedge \bar{1}101) = \sin \alpha\sqrt{\tfrac{3}{4}}, \text{ where } \alpha = (0001 \wedge 10\bar{1}1);$$

in general

$$\sin \tfrac{1}{2}(h0\bar{h}l \wedge \bar{h}h0\bar{l}) = \sin \alpha_{,}\sqrt{\tfrac{3}{4}}, \text{ where } \alpha_{,} = (0001 \wedge h0\bar{h}l).$$

160. Zonal Relations.—The zonal equations, described in Arts. **43**, **44**, apply here as in other systems, only that it is to be noted that one of the indices referring to the lateral axes, preferably the third, i, is to be dropped in the calculations and only the other three employed. Thus the indices (u, v, w) of the zone in which the faces $(hkil)$, $(pqrt)$ lie are given by the scheme

$$\begin{array}{ccccccccc} h & & k & & l & & h & & k \\ & \times & & \times & & \times & & & \\ p & & q & & t & & p & & q \end{array}$$

where $\quad \mathrm{u} = kt - ql, \quad \mathrm{v} = lp - ht, \quad \mathrm{w} = hq - kp.$

For example (Fig. 216), the face μ lies in the zone *ms*, $10\bar{1}0 \cdot 11\bar{2}1$ and also in the zone *m'y*, $01\bar{1}0 \cdot 20\bar{2}1$. For the first zone the values obtained are : $\mathrm{u} = 0$, $\mathrm{v} = \bar{1}$, $\mathrm{w} = 1$; hence for any face in this zone the relation $k = l$ holds true. Similarly for the second zone $e = 1$, $f = 0$, $g = -2$, or $h = 2l$. Therefore the symbol of the given face is given either by the scheme

$$\begin{array}{ccccc} 0 & \bar{1} & 1 & 0 & \bar{1} \\ 1 & 0 & \bar{2} & 1 & 0 \\ \hline & 2 & 1 & 1 & \end{array}$$

or from the two equations $k = l$ and $h = 2l$. The face μ has, therefore, the symbol $21\bar{3}1$, since further $i = -(h + k)$.

161. Formulas.—The following formulas are sometimes useful:

(1) The distances (see Fig. 209) of the pole of any face $(hk\bar{i}l)$ from the poles of the faces $(10\bar{1}0)$, $(01\bar{1}0)$, $(\bar{1}100)$, and (0001) are given by the following equations:

$$\cos \mathrm{PA} = \cos (hk\bar{i}l)(10\bar{1}0) = \frac{\dot{c}(k + 2h)}{\sqrt{3l^2 + 4\dot{c}^2(h^2 + k^2 + hk)}}.$$

$$\cos \mathrm{PB} = \cos (hk\bar{i}l)(01\bar{1}0) = \frac{\dot{c}(2k + h)}{\sqrt{3l^2 + 4\dot{c}^2(h^2 + k^2 + hk)}}.$$

$$\cos \mathrm{PM} = \cos (hk\bar{i}l)(\bar{1}100) = \frac{\dot{c}(h - k)}{\sqrt{3l^2 + 4\dot{c}^2(h^2 + k^2 + hk)}}.$$

$$\cos PC = \cos (hkil)(0001) = \frac{l\sqrt{3}}{\sqrt{3l^2 + 4c^2(h^2 + k^2 + hk)}}.$$

(2) The distance (PQ) between the poles of any two faces P $(hkil)$ and Q $(pq\bar{r}t)$ is given by the equation

$$\cos PQ = \frac{3lt + 2c^2(hq + pk + 2hp + 2kq)}{\sqrt{[3l^2 + 4c^2(h^2 + k^2 + hk)][3t^2 + 4c^2(p^2 + q^2 + pq)]}}.$$

(3) For special cases the above formula becomes simplified; it serves to give the value of the normal angles for the several forms in the system. They are as follows:

(*a*) *Hexagonal Pyramid* $(h0\bar{h}l)$, Fig. 199:

$$\cos X \text{ (terminal)} = \frac{3l^2 + 2h^2c^2}{3l^2 + 4h^2c^2}; \quad \cos Z \text{ (basal)} = \frac{4h^2c^2 - 3l^2}{3l^2 + 4h^2c^2}.$$

(*b*) *Diagonal pyramid* $(h \cdot h \cdot 2\bar{h} \cdot l)$, Fig. 200:

$$\cos Y \text{ (terminal)} = \frac{l^2 + 2c^2h^2}{l^2 + 4c^2h^2}; \quad \cos Z \text{ (basal)} = \frac{4c^2h^2 - l^2}{l^2 + 4c^2h^2}.$$

(*c*) *Dihexagonal Pyramid* $(hkil)$:

$$\cos X \text{ (see Fig. 201)} = \frac{3l^2 + 2c^2(h^2 + k^2 + 4hk)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Y \text{ (see Fig. 201)} = \frac{3l^2 + 2c^2(2h^2 + 2hk - k^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Z \text{ (basal)} = \frac{4c^2(h^2 + k^2 + hk) - 3l^2}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

(*d*) *Dihexagonal Prism* $(hki0)$, Fig. 197:

$$\cos X \text{ (axial)} = \frac{h^2 + k^2 + 4hk}{2(h^2 + k^2 + hk)}. \qquad \cos Y \text{ (diagonal)} = \frac{2h^2 + 2hk - k^2}{2(h^2 + k^2 + hk)}.$$

(*e*) *Rhombohedron* $(10\bar{1}1)$:

$$\cos X \text{ (terminal)} = \frac{3l^2 - 2h^2c^2}{3l^2 + 4h^2c^2}.$$

(*f*) *Scalenohedron* $(hkil)$:

$$\cos X \text{ (see Fig. 242)} = \frac{3l^2 + 2c^2(2k^2 + 2hk - h^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Y \text{ (see Fig. 242)} = \frac{3l^2 + 2c^2(2h^2 + 2hk - k^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

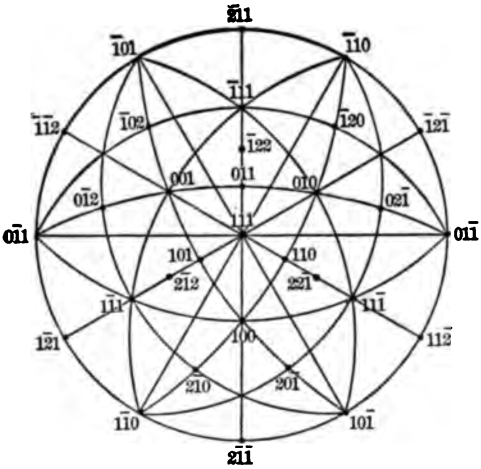
$$\cos Z \text{ (basal)} = \frac{2c^2(h^2 + k^2 + 4hk) - 3l^2}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

162. Angles.—The angles for some commonly occurring prisms are given in the following table:

		m ($10\bar{1}0$, *I*)	*a* ($11\bar{2}0$, *i* 2)
$51\bar{6}0$	i-$\frac{6}{5}$	8° 57′	21° 3′
.$41\bar{5}0$	i-$\frac{5}{4}$	10 53½	19 6½
$31\bar{4}0$	i-$\frac{4}{3}$	13 54	16 6
$52\bar{7}0$	i-$\frac{7}{5}$	16 6	13 54
$21\bar{3}0$	i-$\frac{3}{2}$	19 6½	10 53½
$32\bar{5}0$	i-$\frac{5}{3}$	23 24¾	6 35¼
$54\bar{9}0$	i-$\frac{9}{5}$	26 19¾	3 40¼

163. The Rhombohedral System of Miller.—The following projection (Fig. 273) is added in order to show the relation of the forms in the hexagonal system as referred by Miller to three equal oblique axes parallel to the faces of the fundamental rhombohedron. The forms are as follows:

273.



The faces having the indices 100, 010, 001 are those of the (plus) fundamental rhombohedron, while the face 111 is the base. The faces $22\bar{1}$, $\bar{1}22$, $2\bar{1}2$ are those of the minus fundamental rhombohedron; with 100, 010, 001 they form the unit hexagonal pyramid.

The faces of the hexagonal unit prism, *m* ($10\bar{1}0$), have the symbols $2\bar{1}1$, 112, $\bar{1}2\bar{1}$, $\bar{2}11$, $\bar{1}\bar{1}2$, $1\bar{2}1$. Those of the second, or diagonal, hexagonal prism, *a* ($11\bar{2}0$), have the symbols $10\bar{1}$, $01\bar{1}$, $\bar{1}10$, $\bar{1}01$, $0\bar{1}1$, $1\bar{1}0$.

The dihexagonal pyramid embraces, like the simple hexagonal pyramid, two forms (*hkl*) and (*efg*); of these the symbol (*hkl*) hence belongs to the plus scalenohedron, and (*efg*) to the minus. In this as in other cases it is true that $e = 2h + 2k - l$, $f = 2h - k + 2l$, $g = - h + 2k + 2l$. For example, the faces $2\bar{1}0$, $20\bar{1}$, $02\bar{1}$, $\bar{1}20$, $\bar{1}02$, $0\bar{1}2$ (Fig. 273) belong in the Rhombohedral Division of this system to the scalenohedron ($21\bar{3}1$). The complementary minus scalenohedron would have the faces $52\bar{4}$, etc. The twenty-four faces of these two forms taken together would embrace all the faces of the dihexagonal pyramid of the Hexagonal Division ($21\bar{3}1$). Cf. Fig. 209, p. 70, and Fig. 252, p. 79, with Fig. 273 given here.

Similarly the dihexagonal prism includes the six faces of the form (*hk*0), and the remaining six of the form (*ef*0).

It is seen at once that the indices given above are those of the isometric system, where the cube corresponds to a rhombohedron of 90°; the projection of Fig. 110, p. 41, is brought into relation with the above if an octahedral axis is placed vertical.

The inconvenience of having the faces of the same form (*e.g.*, the dihexagonal prism or pyramid of beryl) represented by two sets of indices is obvious, and this method, introduced by Miller, is now seldom employed. This objection, however, disappears if the axes and indices described are used for rhombohedral forms only, that is, for forms belonging to the groups which are characterized by a vertical axis of trigonal symmetry. This is the method adopted by Groth (1895). It is believed by the author, however, that the mutual relations of all the groups of both divisions of the hexagonal system among themselves (as also to the groups of the tetragonal system), both morphological and physical, are best brought out by keeping throughout the same axes, namely, those of Fig. 193, Art. 115.

IV. ORTHORHOMBIC SYSTEM.

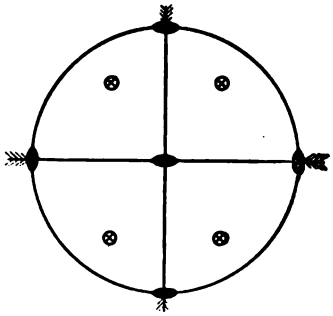
164. The ORTHORHOMBIC SYSTEM includes all the forms which are referred to three unequal axes at right angles to each other.

Of these axes the shorter lateral axis, or *brachy-axis*,[*] is represented by the letter $\breve{a}$, the longer lateral axis, or *macro-axis*, by $\bar{b}$, and the vertical axis by $\dot{c}$ (cf. Fig. 275). In the statement of the axial ratio $\bar{b}$ is uniformly taken as the unit.

1. NORMAL GROUP (25). BARITE TYPE.

165. Symmetry.—The forms of the *normal group* of the orthorhombic system are characterized by three unlike planes of symmetry, at right angles to each other, and further, coincident with their intersection-lines, there are three axes of binary symmetry, which directions are also those of the crystallographic axes. These axes are consequently fixed in position by the symmetry, but any one of them may be made the vertical axis.

274.



The symmetry of the group is exhibited in the accompanying spherical projection, Fig. 274. This should be compared with Fig. 69 (p. 33) and Fig. 148 (p. 53), representing the symmetry of the normal groups of the isometric and tetragonal systems respectively. It will be seen that while normal isometric crystals are developed alike in the three axial directions, those of the tetragonal type have a like development only in the direction of the two lateral axes, and those of the orthorhombic type are unlike in the three axial directions. Compare also Figs. 70 (p. 34), 149 (p. 54), and 275 (p. 90).

166. Forms.—The various forms possible in this group are as follows:

		Miller.		Naumann.
1.	Macropinacoid or a-pinacoid	(100)	$\breve{a} : \infty\bar{b} : \infty\dot{c}$	$\infty P\bar{\infty}$ or i-$\bar{i}$, a
2.	Brachypinacoid or b-pinacoid	(010)	$\infty\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P\breve{\infty}$ or i-$\breve{i}$, b
3.	Base or c-pinacoid	(001)	$\infty\breve{a} : \infty\bar{b} : \dot{c}$	$0P$ or O, c
4.	Unit prism	(110)	$\breve{a} : \bar{b} : \infty\dot{c}$	∞P or I, m
	Macroprisms	$(hk0)$ $h>k$	$\breve{a} : n\bar{b} : \infty\dot{c}$	$\infty P\bar{n}$ or i-$\bar{n}$, as (210) i-$\bar{2}$
	Brachyprisms	$(hk0)$ $h<k$	$n\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P\breve{n}$ or i-$\breve{n}$, as (120) i-$\breve{2}$
5.	Macrodomes	$(h0l)$	$\breve{a} : \infty\bar{b} : m\dot{c}$	$mP\bar{\infty}$ or m-$\bar{i}$, as (201) 2-$\bar{i}$
6.	Brachydomes	$(0kl)$	$\infty\breve{a} : \bar{b} : m\dot{c}$	$mP\breve{\infty}$ or m-$\breve{i}$, as (021) 2-$\breve{i}$
7.	Unit pyramids	(hhl)	$\breve{a} : \bar{b} : m\dot{c}$	mP or m, as (221) 2
		(111)	$\breve{a} : \bar{b} : \dot{c}$	P or 1
	Macropyramids	(hkl) $h>k$	$\breve{a} : n\bar{b} : m\dot{c}$	$mP\bar{n}$ or m-$\bar{n}$, as (211) 2-$\bar{2}$
	Brachypyramids	(hkl) $h<k$	$n\breve{a} : \bar{b} : m\dot{c}$	$mP\breve{n}$ or m-$\breve{n}$, as (121) 2-$\breve{2}$

---

[*] The prefixes *brachy-* and *macro-* used in this system (and also in the triclinic system) are from the Greek words *βραχύς*, *short*, and *μακρός*, *long*.

In general, as defined on p. 26, a *pinacoid* is a form whose faces are parallel to two of the axes, that is, to an axial plane; a *prism* is one whose faces are parallel to the vertical axis, but intersect the two lateral axes; a *dome** is one whose faces are parallel to one of the lateral axes, but intersect in the vertical axis. A dome is sometimes called a *horizontal prism*; a pyramid is a form whose faces meet all the three axes.

These terms are used in the above sense not only in the orthorhombic system, but also in the monoclinic and triclinic systems; in the last each form consist of two planes only.

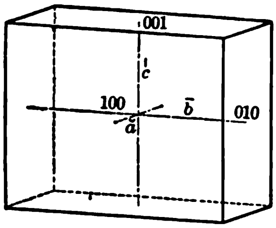
167. Pinacoids.—The *macropinacoid* includes two faces, each of which is parallel both to the macro-axis $\bar{b}$ and to the vertical axis $\dot{c}$; their symbols are respectively 100 and $\bar{1}00$. This form is uniformly designated by the letter *a*, and is conveniently and briefly called the *a-pinacoid.*

The *brachypinacoid* includes two faces, each of which is parallel both to the brachy-axis $\breve{a}$ and to the vertical axis $\dot{c}$; they have the symbols 010 and $0\bar{1}0$. This form is designated by the letter *b*; it is called the *b-pinacoid.*

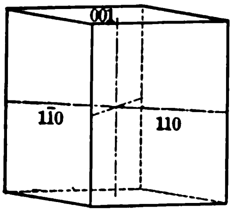
The *base* or *basal pinacoid* includes the two faces parallel to the plane of the lateral axes, and having the symbols 001 and $00\bar{1}$. This form is designated by the letter *c*; it is called the *c-pinacoid.*

Each one of these three pinacoids is an open-form,† but together they make the so-called *diametral prism,* shown in Fig. 275, a solid which is the analogue of the cube of the isometric system. Geometrically it cannot be distinguished from the cube, but it differs in having the symmetry unlike in the three axial directions; practically this may be shown by the unlike physical character of the faces, *a, b, c,* for example as to luster, striations, etc.; or, again, by the cleavage. Further, it is proved at once by optical properties. This diametral prism, as just stated, has three pairs of unlike faces. It has three kinds of edges, four in each set, parallel respectively to the axes $\breve{a}$, $\bar{b}$, and $\dot{c}$; it has, further, eight similar solid angles. In Fig. 275 the dimensions are arbitrarily made to correspond to the relative lengths of the axes, but the student will understand that a crystal of this shape gives no suggestions as to these values.

275



276.



168. Prisms.—The prisms proper include those forms whose faces are parallel to the vertical axis, while they intersect both the lateral axes; their general symbol is, therefore, ($hk0$). These all belong to one type of *rhombic prism,* in which the interfacial angles corresponding to the two unlike vertical edges have different values.

The *unit prism,* (110), is that form whose faces intersect the lateral axes in lengths having a ratio corresponding to the accepted axial ratio of $\breve{a} : \bar{b}$ for the given species; in other words, the angle of this unit prism fixes the unit lengths of the lateral axes. This form is shown in combination with the basal pinacoid in Fig. 276; it is uniformly designated by the letter *m*. The four faces of the unit prism have the symbols 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$.

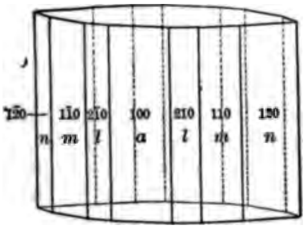
---

* From the Latin *domus,* because resembling the roof of a house; cf. Figs. 279, 280.

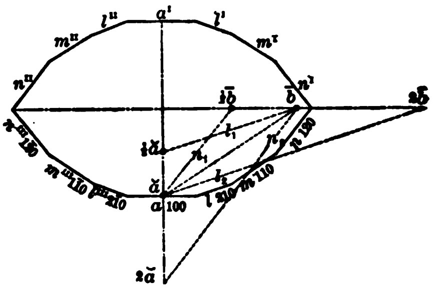
† See p. 25.

The *macroprisms* lie between the macropinacoid, *a* (100), and the unit prism *m* (110), and consequently for them the ratio of *h* to *k* is greater than 1:1; in other words, the ratio of the intercepts on the axes $\bar{b}$ and $\breve{a}$ is greater than that for the unit prism. Common forms have the symbols (410), (310), (210), (320), (430), etc., given in order from 100 toward 110; cf. the spherical projection of Fig. 303. The face *l* of Fig. 277 is the macroprism (210); for this form the axial intercepts (see the basal projection, Fig. 278) are in the ratio of $\frac{1}{2}\breve{a} : 1\bar{b}$, or $1\breve{a} : 2\bar{b}$; a similar relation holds for the other forms (410), etc.

277.



278.



The *brachyprisms* lie between the unit prism and the brachypinacoid *b* (010), and consequently for them the ratio of the first two indices is less than 1:1, or the ratio of the intercepts on $\bar{b}$, $\breve{a}$ is less than that of the unit prism. Common forms are (340), (230), (120), (130), given in order from 110 toward 010. For the form *n* (120), shown in Figs. 277, 278, the axial intercepts are in the ratio of $1\breve{a} : \frac{1}{2}\bar{b}$, or $2\breve{a} : \bar{b}$. Other examples of these prisms are given later (see Figs. 296–299).

In Naumann's symbols the number *n*, the multiple of the lateral axis, is always made greater than unity. Hence while the macroprism, *l*, of Fig. 277 has the full symbol $\breve{a} : 2\bar{b} : \infty\acute{c}$, or briefly $\infty\bar{P}2$ (or $i\text{-}\bar{2}$), the brachyprism is written $2\breve{a} : \bar{b} : \infty\acute{c}$, or $\infty\breve{P}2$ (or $i\text{-}\breve{2}$), instead of the equivalent form $\breve{a} : \frac{1}{2}\bar{b} : \infty\acute{c}$. In other words, with the macroprisms (and macropyramids) the value of the brachy-axis is made equal to unity, while with the brachyprisms (and brachypyramids) the macro-axis is taken as the unit.

169. Macrodomes, Brachydomes.—The *macrodomes* are forms whose faces are parallel to the macro-axis, $\bar{b}$, while they intersect the vertical axis $\acute{c}$ and the lateral axis $\breve{a}$; hence the general symbol is (*h*0*l*). The angle of the unit macrodome, (101), fixes the ratio of the axes $\breve{a} : \acute{c}$. This form is shown in Fig. 279 combined (since it is an open form) with the brachypinacoid.

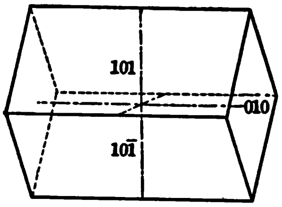
In the macrodome zone between the base *c* (001) and the macropinacoid *a* (100) there may be a large number of macrodomes having the symbols, taken in the order named, (103), (102), (203), (101), (302), (201), (301), etc. Cf. Figs. 298 and 302 described later.

The *brachydomes* are forms whose faces are parallel to the brachy-axis, $\breve{a}$, while they intersect the other axes $\acute{c}$ and $\bar{b}$; their general symbol is (0*kl*). The angle of the unit brachydome, (011), which is shown with *a* (100) in Fig. 280, determines the ratio of the axes $\bar{b} : \acute{c}$.

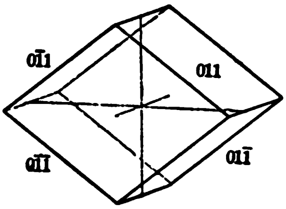
The brachydome zone between *c* (001) and *b* (010) includes the forms (013), (012), (023), (011), (032), (021), (031), etc. Cf. Figs. 298 and 302.

Both sets of domes are often spoken of as *horizontal prisms*. The propriety of this expression is obvious, since they are in fact prisms in geometrical form; further, the choice of position for the axes which makes them domes, instead of prisms in the narrower sense, is more or less arbitrary, as already explained elsewhere.

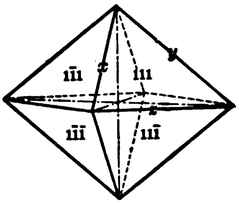
279.



280.



281.



170. Pyramids.—The pyramids in this system all belong to one type, the double *rhombic pyramid*, bounded by eight faces, each a scalene triangle. This form has three kinds of edges, X, Y, Z (Fig. 281; cf. also Fig. 290), each set with a different interfacial angle; two of these angles suffice to determine the axial ratio. The symbol for this, the general form for the system, is (*hkl*).

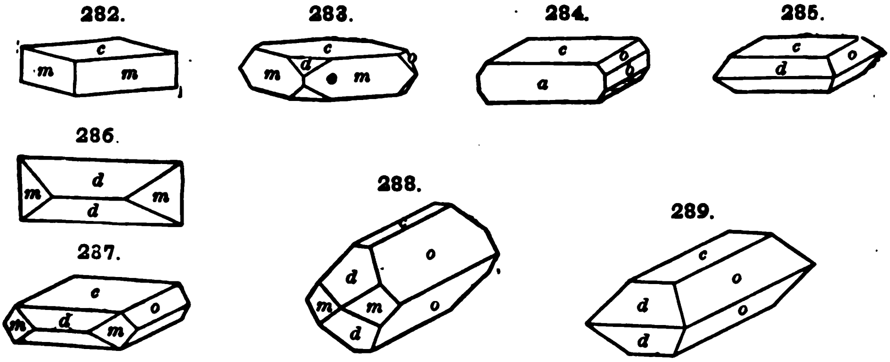
The pyramids fall into three groups corresponding respectively to the three prisms just described, namely, unit pyramids, macropyramids, and brachypyramids.

The *unit pyramids* are characterized by the fact that their intercepts on the lateral axes have the same ratio as those of the unit prism; that is, the assumed axial ratio ($\breve{a} : \bar{b}$) for the given species. For them, therefore, the general symbol becomes (*hhl*).

For different unit pyramids on crystals of the same species the vertical axes may have different lengths bearing usually some simple numerical ratio to each other (and always commensurate), and these form a *zone* of faces lying between the base *c* (001) and the unit prism *m* (110). This zone, for example as shown in the basal projection of a sulphur crystal given in Fig. 302, includes the forms *ψ* (119), *ω* (117), *t* (115), *o* (114), *s* (113), *y* (112), *p* (111). Cf. also Fig. 66, p. 30, of the same species, and the spherical projection, Fig. 303. In the symbol of all of the forms of this zone $h = k$, and the lengths of the vertical axes are hence, in the example given, $\frac{1}{9}$, $\frac{1}{7}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ of the vertical axis $\dot{c}$ of the pyramid *p* (Fig. 290), which in this species is taken as the unit pyramid. The axial ratio for sulphur is given on p. 22.

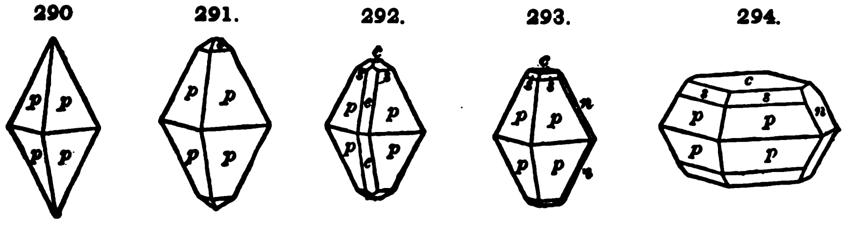
The *macropyramids* and *brachypyramids* are related to each other and to the unit pyramids, as were the macroprisms and brachyprisms to themselves and to the unit prism. Further, each vertical zone of macropyramids (or brachypyramids), having a common ratio for the lateral axes (or of *h* : *k* in the symbol), belongs to a particular macroprism (or brachyprism) characterized by the same ratio. Thus the macropyramids (214), (213), (212), (421), etc., all belong in a common vertical zone between the base (001) and the prism (210). Similarly the brachypyramids (123), (122), (121), (241), etc., fall in a common vertical zone between (001) and (120). Cf. Fig. 299, where *u* and *o* are the brachypyramids (134), (131), falling in the same vertical zone as the brachyprism *d* (130). See also the basal projection, Fig. 302, and the spherical projection, Fig. 303, both of sulphur, noting the relation of the macropyramid (315) to the macroprism (310) and the brachypyramids (135), (133), (131) to the brachyprism (130).

171. Illustrations.—The following figures of barite (282–289) give excellent illustrations of crystals of a typical orthorhombic species, and show also how the habit of one and the same species may vary. The axial ratio for this species is given on p. 96. Here *d* is the macrodome (102) and *o* the unit brachydome (011); *m* is, as always, the unit prism (110). Figs. 282–285 and 287 are described as tabular ‖ *c*; Fig. 286 is prismatic in habit in the direction of the macro-axis ($\bar{b}$), and 288, 289 prismatic in that of the brachy-axis ($\breve{a}$).


282. 283. 284. 285. 286. 287. 288. 289.

Barite Crystals.

Figs. 290–294 of native sulphur show a series of crystals of pyramidal habit with the unit domes *e* (101), *n* (011), and the unit pyramids *p* (111), *s* (113). Note that *e* and *n* truncate respectively the terminal edges of the fundamental pyramid *p*. In general it should be remembered that a macrodome truncating the edge of a pyramid must have the same ratio of *h* : *l*; thus, (201) truncates the edge of (221), etc. Similarly of the brachydomes: (021) truncates the edge of (221), etc. Cf. Figs. 302 and 303.


290 291. 292. 293. 294.

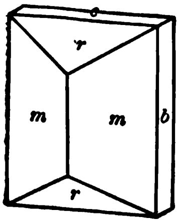
Sulphur Crystals.

Again, Fig. 295, of staurolite, shows the pinacoids *b* (010), *c* (001), the unit prism *m* (110), and the unit macrodome *r* (101).

Figs. 296–298 are prismatic crystals of topaz. Here *m* is the unit prism (110); *l* and *n* are the brachyprisms (120), (140); *d* and *ρ* are the macrodomes (201) and (401); *f* and *y* are the brachydomes (021) and (041); *i*, *u*, and *o* are the unit pyramids (223), (111), (221).

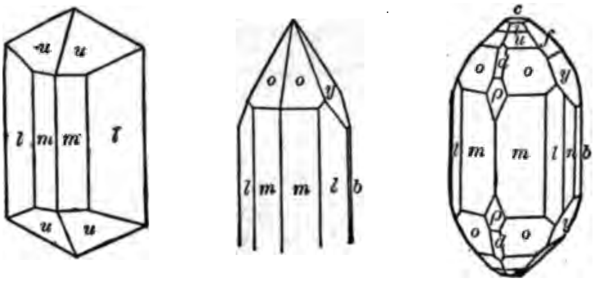
In Fig. 299, of iolite, *s* and *r* are the unit pyramids (112), (111); *d* is the brachyprism (130), and *u*, *o* are the corresponding brachypyramids (134), (131). Fig. 300, of brookite, simulates a tetragonal crystal since the prismatic angle is not very far from 90°; here $z = (112)$. In Fig. 301 of the same species, *e* is the brachypyramid (122); this crystal closely resembles an hexagonal pyramid with its axis placed horizontal since the angles *me* (110 $\wedge$ 122) and *ee'* (122 $\wedge$ $\bar{1}22$) are approximately equal.

295.



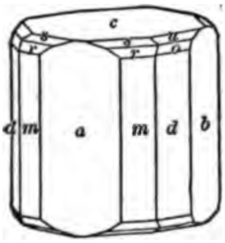
Staurolite.

296. 297. 298.



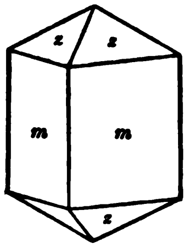
296–298 Topaz.

299.



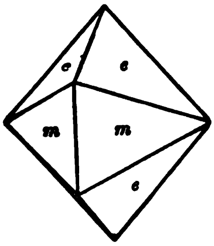
Iolite.

300.



Brookite.

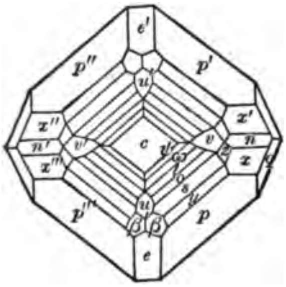
301.



Brookite.

172. Projections.— Basal and spherical projections of a typical orthorhombic species have already been given in Figs. 63 and 65 on pp. 27, 28. The subject is so important, however, that others are given here (Figs. 302, 303) for the species sulphur, cf. Figs. 290–294, also Fig. 66, p. 30. In Fig. 303 besides the pinacoids *a* (100), *b* (010), *c* (001), the positions of the prisms* (310), *m* (110), (130) are shown; the macrodomes *u* (103), *e* (101) and the brachydomes *v* (013), *n* (011); the remarkable zone of unit pyramids *ψ* (119), *ω* (117), *t* (115), *o* (114), *s* (113), *y* (112), *p* (111); finally the macropyramid *β* (315) and the brachypyramids *z* (135) and *x* (133). Both projections exhibit clearly the symmetry

302.

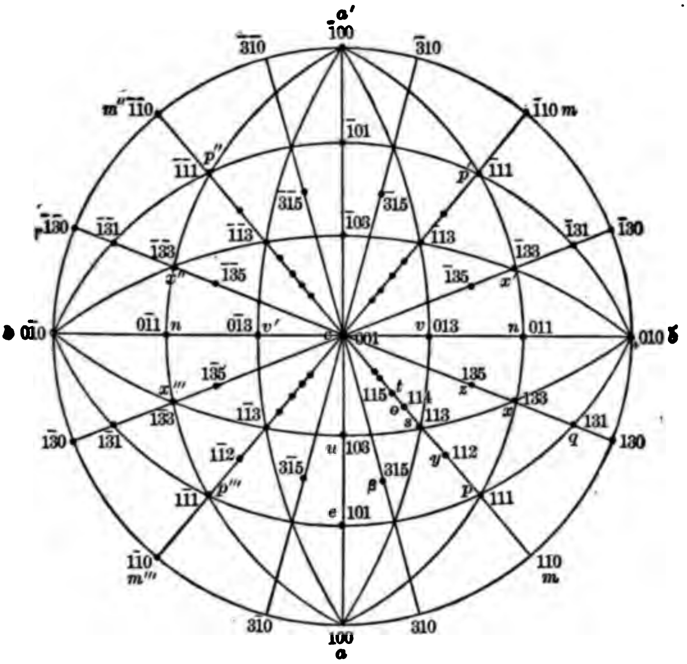


---

*The prism *m* is not shown in Fig. 302, but is added here for sake of completeness; also (310), (130), forms not yet observed on this species.

characteristic of the group; the prominent zones, already spoken of, should also be noted.

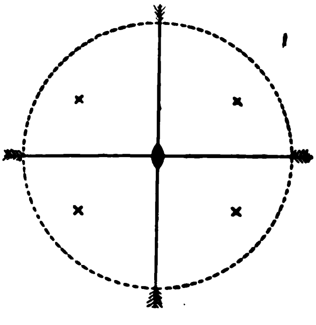
303.



2. HEMIMORPHIC GROUP (26). CALAMINE TYPE.

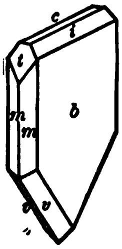
173. Symmetry and Typical Forms.—The forms of the *orthorhombic-hemimorphic* group are characterized by two unlike planes of symmetry and one axis of binary symmetry, the line in which they intersect; there is no center of symmetry. The forms are therefore hemimorphic, as defined in Art. **29**. For example, if, as is usually the case, the vertical axis is made the axis of symmetry, the two planes of symmetry are parallel to the pinacoids *a* (100) and *b* (010). The prisms are then geometrically like those of the normal group, as are also the macropinacoid and brachypinacoid; but the two basal planes become two independent forms, (001) and (00$\bar{1}$). There are also two macrodomes, (101) and (10$\bar{1}$), or in general (*h*0*l*) and (*h*0$\bar{l}$); and similarly two sets, for a given symbol, of brachydomes and pyramids.

304.

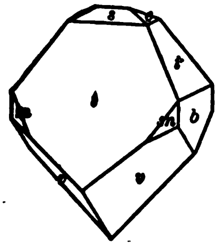


The general symmetry of the group is shown in the spherical projection of Fig. 304. Further, Figs. 305, 306, of calamine, and 307, of struvite, represent typical crystals of this group. In Figs. 305, 306 the forms present are *t* (301), *s* (101), *i* (031), *e* (011), *v* $(12\bar{1})$; in Fig. 307 they are *s* (101), s_1 $(10\bar{1})$, *q* (011).

305.

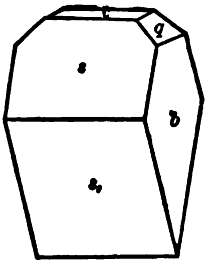


306.



Calamine.

307.

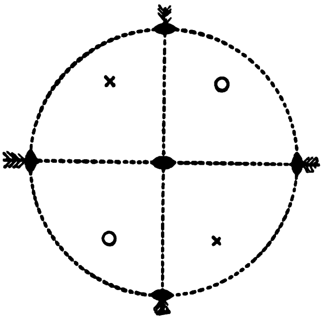


Struvite.

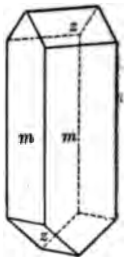
3. SPHENOIDAL GROUP (27). EPSOMITE TYPE.

174. Symmetry and Typical Forms.—The forms of the remaining group of the system, the *orthorhombic-sphenoidal* group, are characterized by three unlike rectangular axes of binary symmetry, but they have no plane and no center of symmetry (Fig. 308). The general form *hkl* here has four faces only, and the corresponding solid is a rhombic sphenoid, analogous to the sphenoid of the tetragonal system. The complementary plus and minus sphenoids are enantiomorphous. Fig. 309 represents a typical crystal, of epsomite, with the plus sphenoid, *z* (111). Other crystals of this species often show both plus and minus complementary forms, but usually unequally developed.

308.



309.



Epsomite.

Mathematical Relations of the Orthorhombic System.

175. Choice of Axes.—As explained in Art. 165, the three crystallographic axes are fixed as regards direction in all orthorhombic crystals, but any one of them may be made the vertical axis, $\dot{c}$; and of the two lateral axes, which is the longer ($\bar{b}$) and which the shorter ($\breve{a}$) cannot be determined until it is decided which faces to assume as the fundamental, or unit, pyramid, prism, or domes.

The choice is generally so made, in a given case, as to best bring out the relation of the crystals of the species in hand to others allied to them in form or in chemical composition, or in both respects; or, so as to make the cleavage parallel to the fundamental form; or, as suggested by the common habit of the crystals, or other considerations.

176. Axial and Angular Elements.—The *axial elements* are given by the ratio of the lengths of the three axes in terms of the macro-axis, $\bar{b}$, as unity. For example, with barite the axial ratio is

$$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}81520 : 1 : 1{\cdot}31359.$$

The *angular elements* are usually taken as the angles between the three pinacoids and the unit faces in the three zones between them. Thus, again for barite, these elements are

$$100 \wedge 110 = 39^\circ\ 11'\ 18'', \quad 001 \wedge 101 = 58^\circ\ 10'\ 36'', \quad 001 \wedge 011 = 52^\circ\ 43'\ 8''.$$

Two of these angles obviously determine the third angle as well as the axial ratio. The degree of accuracy to be attempted in the statement of the axial ratio depends upon the character of the fundamental measurements from which this ratio has been deduced. There is no good reason for giving the values of $\breve{a}$ and $\breve{c}$ to many decimal places if the probable error of the measurements amounts to many minutes. In the above case the measurements (by Helmbacker) are supposed to be accurate within a few seconds. It is convenient, however, to have the angular elements correct, say, within 10″, so that the calculated angles obtained from them will not vary from those derived direct from the measured angles by more than 30″ to 1′.

177. Calculation of the Axes.—The following simple relations (cf. Art. 46) connect the axes with the angular elements:

$$\tan(100 \wedge 110) = \breve{a}, \quad \tan(001 \wedge 011) = \breve{c}, \quad \tan(001 \wedge 101) = \frac{\breve{c}}{\breve{a}}.$$

These equations serve to give either the axes from the angular elements, or the angular elements from the axes. It will be noted that the axes are not needed for simple purposes of calculation, but it is still important to have them, for example to use in comparing the morphological relations of allied species.

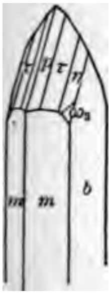
In practice it is easy to pass from the measured angles, assumed as the basis of calculation (or deduced from the observations by the method of least squares), to the angular elements, or from either to any other angles by the application of the tangent principle (Art. 47) to the pinacoidal zones, and by the solution of the right-angled spherical triangles given on the sphere of projection.

Thus any face *hkl* (see p. 28) lies in the three pinacoidal zones, 100 and 0*kl*, 010 and *h*0*l*, 001 and *hk*0. For example, the position of the face, 321, is fixed if the positions of two of the poles, 301, 021, 320, are known. These last are given, respectively, by the equations

$$\tan(001 \wedge 301) = 3 \times \tan(001 \wedge 101), \quad \tan(001 \wedge 021) = 2 \times \tan(001 \wedge 011),$$
$$\tan(100 \wedge 320) = \tfrac{2}{3} \times \tan(100 \wedge 110).$$

178. Example—Fig. 310 represents a crystal of stibnite from Japan, with the faces *p* (111), *r* (343), *η* (353), etc. On this the following measured angles were taken as fundamental:

310.



$$\eta\eta' \ (353 \wedge \bar{3}53) = 55° \ 1' \ 0'',$$
$$\eta\eta''' \ (353 \wedge 3\bar{5}3) = 99° \ 39' \ 0''.$$

Hence, the angles 353 ∧ 010 = 40° 10½′ and 353 ∧ 053 = 27° 30½′ are known without calculation. The right-angled spherical triangle* 010 · 053 · 353 yields the angle (010 ∧ 053) and hence (001 ∧ 053); also the angle at 010, which is equal to (001 ∧ 101). But $\tan(001 \wedge 011) = \frac{3}{5} \times \tan(001 \wedge 053)$, and $\tan(001 \wedge 011) = \breve{c}$. Also since $\tan(001 \wedge 101) = \frac{\breve{c}}{\breve{a}}$, the axial ratio is thus known, and two of the angular elements.

The third angular element (001 ∧ 110) can be calculated independently, for the angle at 001 in the triangle 001·053·353 is equal to (010 ∧ 350) and $\tan(010 \wedge 350) \times \frac{5}{3} = (010 \wedge 110)$, the complement of (100 ∧ 110).

Then since $\tan(100 \wedge 110) = \breve{a}$, this can be used to check the value of $\breve{a}$ already obtained. The further use of the tangent principle with the occasional solution of a right-angled triangle will serve to give any desired angle from either the fundamental angles direct, or from the angular elements.

Again, the symbol of any unknown face can be readily calculated if two measured angles of tolerable accuracy are at hand. For example, for the face *ω*, suppose the measured angles to be

$$b\omega \ (010 \wedge hkl) = 30° \ 15', \quad \omega\omega' \ (\underset{\smile}{h}kl \wedge hkl) = 51° \ 32'.$$

The solution of the triangle *b*·*ω*·0*kl* gives the angle (010 ∧ 0*kl*) = 16° 25′ 20″, and

$$\frac{\tan(001 \wedge 0kl)}{\tan(001 \wedge 011)} = \frac{\tan 73° \ 34\frac{2}{3}'}{\tan 45° \ 30\frac{1}{2}'} = 3{\cdot}333 +, = \frac{k}{l}.$$

---

* The student in this as in every similar case should draw a spherical projection (not necessarily accurately constructed) to show, if only approximately, the relative position of the faces present.

But the ratio of $k : l$ must be rational and the number derived agrees most closely with 10 : 3.

Again, the angle $(001 \wedge h0l)$ may now be calculated from the same triangle and the value 59° $38\frac{3}{4}'$ obtained. From this the ratio of h to l is derived since

$$\frac{\tan\,(001 \wedge h0l)}{\tan\,(001 \wedge 101)} = \frac{\tan\,59^\circ\,38\frac{3}{4}'}{\tan\,45^\circ\,43\frac{1}{4}'} = 1{\cdot}665 = \frac{h}{l}.$$

This ratio is nearly equal to 5 : 3, and the two values thus obtained give the symbol 5·10·3. If, however, from the triangle 001·0kl·ω, the angle at 001 is calculated, the value 26° $42\frac{3}{4}'$ is obtained, which is also the angle $(010 \wedge hk0)$. From this the ratio $h : k$ is deduced, since

$$\frac{\tan\,(010 \wedge 110)}{\tan\,(010 \wedge hk0)} = \frac{\tan\,45^\circ\,12\frac{3}{4}'}{\tan\,26^\circ\,42\frac{3}{4}'} = 2{\cdot}002 = \frac{k}{h}.$$

The value of $\frac{k}{h}$ is hence closely equal to 2; this combined with that first obtained $\left(\frac{k}{l} = \frac{10}{3}\right)$ gives the same symbol 5·10·3.

This symbol being more than usually complex calls for fairly accurate measurements. How accurate the symbol obtained is can best be judged by comparing the measured angles with those calculated from the symbol. For example, in the given case the calculated angles for ω (5 10·3) are $b\omega$ $(010 \wedge 5{\cdot}10{\cdot}3) = 30^\circ\,16'$, $\omega\omega'$ $(5{\cdot}10{\cdot}3 \wedge \bar{5}{\cdot}10{\cdot}3) = 51^\circ\,35'$. The correctness of the value deduced is further established if it is found that the given face falls into prominent zones.

It will be understood further that the zonal relations, explained on pp. 29, 30, play an important part in all calculations. For example, in Fig. 310, if the symbol of r were unknown, it could be obtained from a single angle (as br), since for this zone $h = l$.

179. Formulas.—Although it is not often necessary to employ formulas in calculations, a few are added here for sake of completeness.

(1) For the distance between the pole of any face P (hkl) and the pinacoids a, b, c, we have in general:

$$\cos^2 \mathrm{P}a = \cos^2\,(hkl \wedge 100) = \frac{h^2c^2}{hc^2 + k^2a^2c^2 + l^2a^2};$$

$$\cos^2 \mathrm{P}b = \cos^2\,(hkl \wedge 010) = \frac{k^2a^2c^2}{h^2c^2 + k^2a^2c^2 + l^2a^2};$$

$$\cos^2 \mathrm{P}c = \cos^2\,(hkl \wedge 001) = \frac{l^2a^2}{h^2c^2 + k^2a^2c^2 + l^2a^2}.$$

Here a and c in the formulas are the two axes $\breve{a}$ and $\dot{c}$.

(2) For the distance (PQ) between the poles of any two faces (hkl) and (pqr):

$$\cos \mathrm{PQ} = \frac{hpc^2 + kqa^2c^2 + lra^2}{\sqrt{[h^2c^2 + k^2a^2c^2 + l^2a^2][p^2c^2 + q^2a^2c^2 + r^2a^2]}}.$$

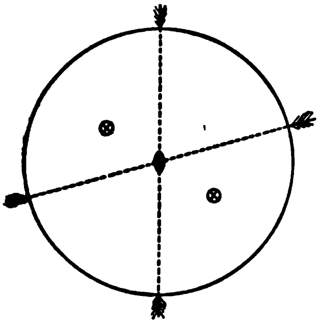
V. MONOCLINIC SYSTEM.

180. The MONOCLINIC SYSTEM includes all the forms which are referred to three unequal axes, having one of their axial inclinations oblique.

The axes are designated as follows: the inclined or clinodiagonal axis is $\breve{a}$; the orthodiagonal axis is $\bar{b}$, the vertical axis is $\dot{c}$. The acute angle between the axes $\breve{a}$ and $\dot{c}$ is represented by the letter β; the angles between $\breve{a}$ and $\bar{b}$ and $\bar{b}$ and $\dot{c}$ are right angles. See Fig. 312. Crystals are usually drawn with the axis $\dot{c}$ vertical and the axis $\breve{a}$ directed to the front and inclined downward.

1. NORMAL GROUP (28). GYPSUM TYPE.

311.



181. Symmetry.—In the normal group of the monoclinic system there is one plane of symmetry and one axis of binary symmetry normal to it. The plane of symmetry is always the plane of the axes $\grave{a}$ and $\dot{c}$, and the axis of symmetry coincides with the axis $\bar{b}$, normal to this plane. The position of one axis ($\bar{b}$) and that of the plane of the other two axes ($\grave{a}$ and $\dot{c}$) is thus fixed by the symmetry; but the latter axes may occupy different positions in this plane. Fig. 311 shows the typical spherical projection, projected on the plane of symmetry. Fig. 327 is the projection of an actual crystal of epidote; here, as is usual, the plane of projection is normal to the prismatic zone.

182. Forms.—The various forms* belonging to this group, with their symbols, are given in the following table. As more particularly explained later, an orthodome includes two faces only, and a pyramid four only.

	Miller.		Naumann.
1. Orthopinacoid or *a*-pinacoid	(100)	$\grave{a}:\infty\bar{b}:\infty\dot{c}$	$\infty P\bar{\infty}$ or $i\text{-}\bar{i}$, a
2. Clinopinacoid or *b*-pinacoid	(010)	$\infty\grave{a}:\bar{b}:\infty\dot{c}$	$\infty P\grave{\infty}$ or $i\text{-}\grave{i}$, b
3. Base or *c*-pinacoid	(001)	$\infty\grave{a}:\infty\bar{b}:\dot{c}$	$0P$ or O, c
4. Unit prism	(110)	$\grave{a}:\bar{b}:\infty\dot{c}$	∞P or I, m
Orthoprisms	$(hk0)$ $h>k$	$\grave{a}:n\bar{b}:\infty\dot{c}$	$\infty P\bar{n}$ or $i\text{-}\bar{n}$, as (210) $i\text{-}\bar{2}$
Clinoprisms	$(hk0)$ $h<k$	$n\grave{a}:\bar{b}:\infty\dot{c}$	$\infty P\grave{n}$ or $i\text{-}\grave{n}$, as (120) $i\text{-}\grave{2}$
5. Orthodomes	$(h0l)$	$\grave{a}:\infty\bar{b}:m\dot{c}$	$-mP\bar{\infty}$ or $-m\text{-}\bar{i}$, as (101) $-1\text{-}\bar{i}$
	$(\bar{h}0l)$	$\grave{a}:\infty\bar{b}:-m\dot{c}$	$mP\infty$ or $m\text{-}\bar{i}$, as $(\bar{1}01)$ $1\text{-}\bar{i}$
6. Clinodomes	$(0kl)$	$\infty\grave{a}:\bar{b}:m\dot{c}$	$mP\grave{\infty}$ or $m\text{-}\grave{i}$, as (011) $1\text{-}\grave{i}$
7. Unit pyramids	(hhl)	$\grave{a}:\bar{b}:m\dot{c}$	$-mP$ or $-m$, as (111) -1
	$(\bar{h}hl)$	$\grave{a}:\bar{b}:-m\dot{c}$	mP, as $(\bar{1}11)$ 1
Orthopyramids	(hkl) $h>k$	$\grave{a}:n\bar{b}:m\dot{c}$	$-mP\bar{n}$ or $-m\text{-}\bar{n}$, as (211)$-2\text{-}\bar{2}$
	$(\bar{h}kl)$ $h>k$	$\grave{a}:n\bar{b}:-m\dot{c}$	$mP\bar{n}$ or $m\text{-}n$, as $(\bar{2}11)$ $2\text{-}\bar{2}$
Clinopyramids	(hkl) $h<k$	$n\grave{a}:\bar{b}:m\dot{c}$	$-mP\grave{n}$ or $-m\text{-}\grave{n}$, as (121)$-2\text{-}\grave{2}$
	$(\bar{h}kl)$ $h<k$	$n\grave{a}:\bar{b}:-m\dot{c}$	$mP\grave{n}$ or $m\text{-}\grave{n}$, as (121) $2\text{-}\grave{2}$

The Naumann symbols given above are analogous to those of the orthorhombic system. The long mark employed is to be understood to be conventional only and as referring to the ortho-axis, $\bar{b}$. It does not imply that this axis is longer than the clino-axis, $\grave{a}$, though this is commonly the case. The inclined mark refers to the inclined axis, $\grave{a}$. With some authors these marks pass through the P, instead of being written over the letter (or number) following.

---

* **On the general use of the terms pinacoid, prisms, domes, pyramids, see pp. 26, 90.**

183. Pinacoids.—The pinacoids are the orthopinacoid, clinopinacoid, and the basal plane.

The *orthopinacoid*, (100), includes the two faces parallel to the plane of the ortho-axis, b̄ and the vertical axis ċ. They have the symbols 100 and $\bar{1}00$. This form is designated by the letter *a*, since it is situated at the extremity of the ă axis; it is hence conveniently called the *a-pinacoid.*

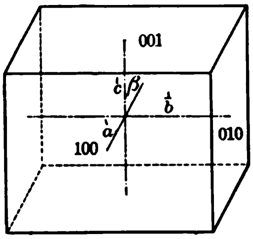
The *clinopinacoid*, (010), includes the two faces parallel to the plane of symmetry; that is, the plane of the clino-axis ă and to the axis ċ. They have the symbols 010 and $0\bar{1}0$. The clinopinacoid is designated by the letter *b*, and is called the *b-pinacoid.*

The *base* or *basal pinacoid*, (001), includes the two terminal faces, above and below, parallel to the plane of the lateral axes ă, b̄; they have the symbols 001 and $00\bar{1}$. The base is designated by the letter *c*, and is often called the *c-pinacoid.* It is obviously inclined to the orthopinacoid, and the normal angle between the two faces (100 ∧ 001) is the acute axial angle *β*.

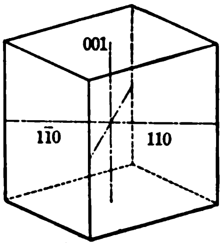
The diametral prism, formed by these three pinacoids, taken together, Fig. 312, is the analogue of the cube in the isometric system. It is bounded by three sets of unlike faces; it has four similar vertical edges; also four lateral similar edges parallel to the axis ă, but the remaining edges, parallel to the axis b̄, are only similar two-and-two. Of its eight solid angles there are two sets of four each; the two above in front are similar to those below behind, and the two below in front to those behind above.

184. Prisms.—The prisms are all of one type, the oblique rhombic prism. They include the *unit prism,* (110), designated by the letter *m*, shown in Fig. 313; also the *orthoprisms,* $(hk0)$ where $h > k$, lying between *a* (100) and *m* (110), and the *clinoprisms,* $(hk0)$ where $h < k$, lying between *m* (110) and *b* (010). The orthoprisms and clinoprisms correspond respectively to the macroprisms and brachyprisms of the orthorhombic system, and the explanation on p. 91 will hence make their relation clear. Common cases of these prisms are shown in the figures given later.

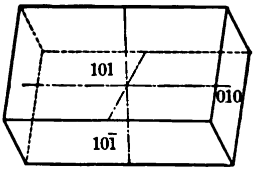
312.



313.



314.



185. Orthodomes.—The four faces parallel to the ortho-axis b̄, and meeting the other two axes, fall into two sets of two each, having the general symbols $(h0l)$ and $(\bar{h}0l)$. These forms are called *orthodomes,* they are strictly hemi-orthodomes. For example, the unit orthodome (101) has the faces 101 and $\bar{1}0\bar{1}$; they would replace the two obtuse edges between *a* (100) and *c* (001) in Fig. 312. The other unit orthodome ($\bar{1}01$) has the faces $\bar{1}01$ and $10\bar{1}$, and they would replace the acute edges between *a* and *c*. These two independent forms are shown together, with *b* (010), in Fig. 314.

Similarly the faces 201, $\bar{2}0\bar{1}$ belong to the form (201), and $\bar{2}01$, $20\bar{1}$ to the independent but complementary form ($\bar{2}01$).

In the symbols of Naumann, the hemi-orthodomes between the base and the front orthopinacoid above, and hence corresponding to the obtuse edge between them, are distinguished by the minus sign (— 1-ī = 101, etc.), while those between the base and the orthopinacoid behind are called plus* (+ 1-ī = $\bar{1}01$); the + sign, however, is usually omitted. The two sets of hemi-pyramids (see beyond) are similarly distinguished.

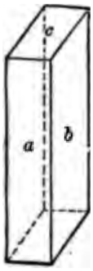
186. Clinodomes.—The *clinodomes* are the forms whose faces are parallel to the inclined axis, *à*, while intersecting the other two axes. Their general symbol is hence (0*kl*) and they lie between the base (001) and the clinopinacoid (010). Each form has four faces; thus for the unit clinodome these have the symbols, 011, $0\bar{1}1$, $0\bar{1}\bar{1}$, $01\bar{1}$. The form *n* (021) in Fig. 321 is a clinodome.

187. Pyramids.—The *pyramids* in the monoclinic system are all hemi-pyramids, embracing four faces only in each form, corresponding to the general symbol (*hkl*). This obviously follows from the symmetry; it is shown, for example, in the fact already stated that the solid angles of the diametral prism (Fig. 312, see above), which are replaced by these pyramids, fall into two sets of four each. Thus any general symbol, as (321), includes the two independent forms (321) and ($\bar{3}21$) with the faces

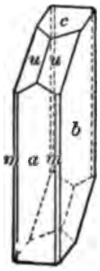
321, $3\bar{2}1$, $\bar{3}2\bar{1}$, $\bar{3}\bar{2}\bar{1}$, and $\bar{3}21$, $\bar{3}\bar{2}1$, $32\bar{1}$, $3\bar{2}\bar{1}$.

The pyramids may be *unit pyramids*, (*hhl*), orthopyramids, (*hkl*) when *h* > *k*, or *clinopyramids*, (*hkl*) when *h* < *k*. These correspond respectively to the three prisms already named. They are analogous also to the unit pyramids, macropyramids and brachypyramids of the orthorhombic system, and the explanation given on pp. 91, 92 should serve to make their relations clear. But it must be remembered that each general symbol embraces two forms, (*hhl*) and ($\bar{h}kl$) with four faces each, as above explained.

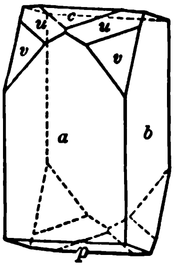
315.



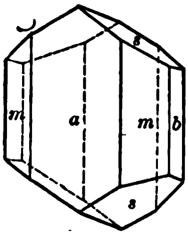
316.



317.



318.



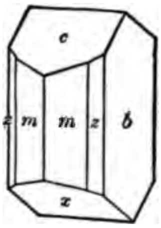
Pyroxene.

188. Illustrations.—Figs. 315–318 of pyroxene ($\grave{a}:\bar{b}:\dot{c}$ = 1·092 : 1 : 0·589, β = 74° = *ac*) show typical monoclinic forms. Fig. 315 shows the diametral prism. Of the other forms, *m* is the unit prism (110); *p* $(\bar{1}01)$ is an orthodome; *u* (111), *v* (221), *s* $(\bar{1}11)$ are unit pyramids; for other figures see p. 387. Again, Figs. 319–321 represent common crystals of orthoclase ($\grave{a} : \bar{b} : \dot{c} = 0{\cdot}659 : 1 : 0{\cdot}555$, $\beta = 64^\circ = ac$). Here *z* (130) is a clinoprism; *x* $(\bar{1}01)$ and *y* $(\bar{2}01)$ are orthodomes; *n* (021) is a clinodome; *o* $(\bar{1}11)$ a unit pyramid. Since (Fig. 319) *c* and *x* happen to make nearly equal angles with the vertical edge of the prism *m*, the combination often stimulates an orthorhombic crystal.

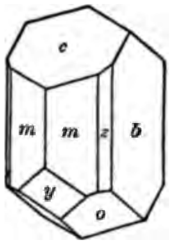
---

* This choice of signs by Naumann was unfortunate, being contrary to ordinary usage; it is, however, too generally accepted to admit of being reversed. He was led to adopt it because the internal angle of the upper front edge between 001 and 100 is obtuse and hence the cosine (*e.g.* in the general cosine formula for the angle between two faces) is *negative.*

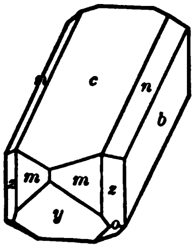
319.



320.



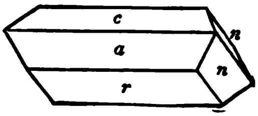
321.



Orthoclase.

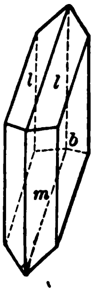
Fig. 322 shows a monoclinic crystal, epidote, prismatic in the direction of the ortho-axis; the forms are *r* $(\bar{1}01)$ and *n* $(\bar{1}11)$. Fig. 323 of gypsum is flattened ‖ *b*; it shows the unit pyramid *l* (111) with the unit prism *m* (110). Fig. 324 of monazite is prismatic in habit by extension of the pyramid *v* $(\bar{1}11)$. It shows also the orthodome *w* (101); the clinodome *e* (011); the pyramids *r* (111), *s* (121), *z* $(\bar{3}11)$, *i* $(\bar{2}11)$.

322.



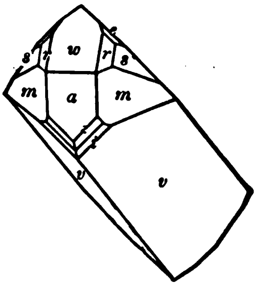
Epidote.

323.



Gypsum.

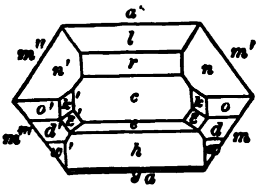
324.



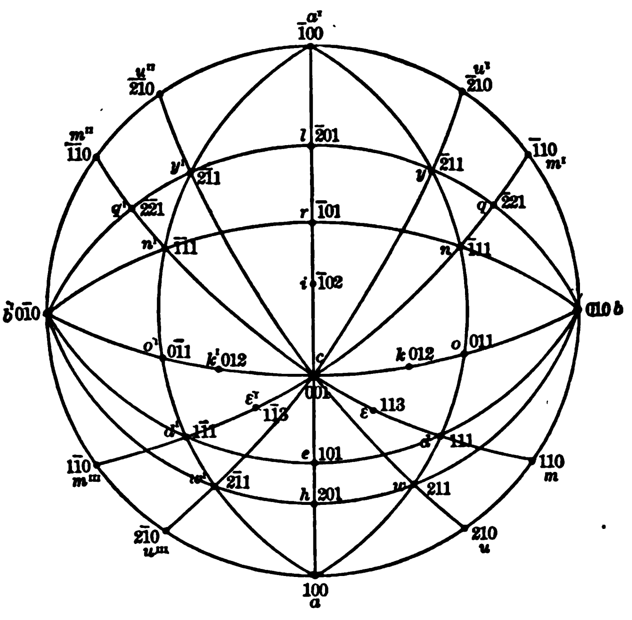
Monazite.

189. Projections.—Fig. 325 shows a projection of a crystal of epidote (cf. Fig. 853, p. 438) on a plane normal to the prismatic zone, and Fig. 326 one of a similar crystal on a plane parallel to *b* (010); both should be carefully studied, as also the spherical projection of the same species, Fig. 327. The symbols of the prominent faces are given in Fig. 327.

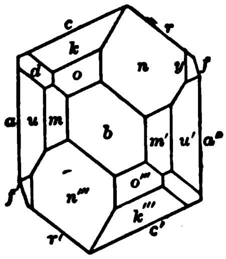
325.



327.



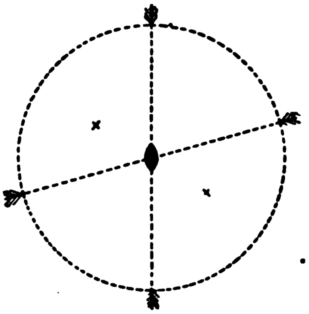
326.



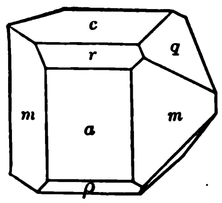
2. HEMIMORPHIC GROUP (29).

190. The *monoclinic-hemimorphic* group is characterized by a single axis of binary symmetry, the crystallographic axis *b*, but it has no plane of symmetry. It is illustrated by the spherical projection (Fig. 328); also by Fig. 329, a common form of tartaric acid; sugar crystals also belong here.

328.



329.



Tartaric Acid.
Forms: *r* (101), *ρ* (101), *q* (011).

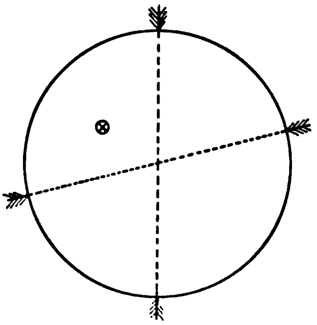
The hemimorphic character is distinctly shown in the distribution of the clinodomes and pyramids; corresponding to this the artificial salts belonging here often exhibit marked pyro-electrical phenomena.

3. CLINOHEDRAL GROUP (30). CLINOHEDRITE TYPE.

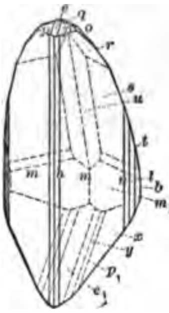
191. The *monoclinic-clinohedral* group (the domatic class of Groth) is characterized by a single plane of symmetry, parallel to the clinopinacoid, *b* (010), but it has no axis of symmetry (cf. Fig. 330). In this group, therefore, the forms parallel to the $\breve{b}$-axis, viz., *c* (001), *a* (100) and the orthodomes, are represented by a single face only. The other forms have each two faces, but it is to be noted that, with the single exception of the clinopinacoid *b* (010), the faces of a given form are never parallel to another. The name given to the group is based on this fact.

Several artificial salts belong here in their crystallization, but the only known representative among minerals is the rare silicate, clinohedrite ($H_2CaZnSiO_4$),* a complex crystal of which is shown in two positions in Figs. 331, 331*a*. As seen in these figures, the crystals of the group have a hemimorphic aspect with respect to their development in the direction of the vertical axis, although they cannot properly be called hemimorphic since this is not an axis of symmetry. The forms shown in Figs. 331, 331*a* are as follows: pinacoid, *b* (010); prisms, *m* (110), m_1 ($\bar{1}10$), *h* (320), *n* (120), *l* (130); orthodomes, *e* (101), e_1 ($\bar{1}0\bar{1}$); pyramids, *p* (111), p_1 ($\bar{1}1\bar{1}$), *q* ($\bar{1}11$); *r* ($\bar{3}31$), *s*, ($\bar{5}51$), *t* ($\bar{7}71$), *u* ($\bar{5}31$), *o* ($\bar{1}31$), *x* ($\bar{1}3\bar{1}$), *y* ($\bar{1}2\bar{1}$).

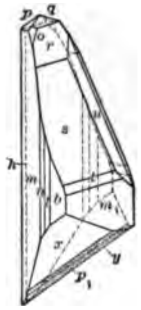
330.



331.



331*a*.



Clinohedrite.

It is to be noted that crystals of the common species pyroxene (also of ægirite and titanite) occasionally show this habit in the distribution of their faces, but it is not certain that this may not be accidental.†

Mathematical Relations of the Monoclinic System.

192. Choice of Axes.—It is repeated here (Art. 181), that the fixed position of the plane of symmetry establishes the direction of the axis $\breve{b}$ and the plane of the axes $\grave{a}$ and $\acute{c}$. The latter axes, however, may have varying positions in this plane according as to which faces are taken as the pinacoids *a* and *c*, and which the unit pyramid, prism, or domes.

193. Axial and Angular Elements.—The *axial elements* are the *lengths* of the axes $\grave{a}$ and $\acute{c}$ in terms of the unit axis $\breve{b}$, that is, the axial ratio, with also the acute angle of inclination of the axes $\grave{a}$ and $\acute{c}$, called β. Thus for orthoclase the axial elements are:

$$\grave{a} : \breve{b} : \acute{c} = 0{\cdot}6585 : 1 : 0{\cdot}5554 \quad \beta = 63^\circ\ 56\tfrac{3}{4}'.$$

---

* Penfield and Foote, Am. J. Sc., 5. 289, 1898.

† See G. H. Williams, Am. J. Sc., 34, 275, 1887, 38, 115, 1889.

The angular elements are usually taken as the angle (100 $\wedge$ 001) which is equal to the angle β; also the angles between the three pinacoids 100, 010, 001, respectively, and the unit prism 110, the unit orthodome (101 or $\bar{1}01$) and the unit clinodome 011. Thus again for orthoclase, the angular elements are:

$$001 \wedge 100 = 63^\circ\ 56\tfrac{3}{4}', \quad 100 \wedge 110 = 30^\circ\ 36\tfrac{1}{2}'.$$
$$001 \wedge \bar{1}01 = 50^\circ\ 16\tfrac{1}{2}', \quad 001 \wedge 011 = 26^\circ\ 31'.$$

194. The mathematical relations connecting axial and angular elements are as follows:

$$\grave{a} = \frac{\tan(100 \wedge 110)}{\sin\beta} \quad \text{or} \quad \tan(100 \wedge 110) = \grave{a}\,.\sin\beta; \tag{1}$$

$$\grave{c} = \frac{\tan(001 \wedge 011)}{\sin\beta} \quad \text{or} \quad \tan(001 \wedge 011) = \grave{c}\,.\sin\beta; \tag{2}$$

$$\left.\begin{aligned} \grave{c} &= \frac{\grave{a}\,.\tan(001 \wedge 101)}{\sin\beta - \cos\beta\,.\tan(001 \wedge 101)} \quad \text{or} \quad \tan(001 \wedge 101) = \frac{\grave{c}\sin\beta}{\grave{a} + \grave{c}\,.\cos\beta}, \\ \grave{c} &= \frac{\grave{a}\,.\tan(001 \wedge \bar{1}01)}{\sin\beta + \cos\beta\,.\tan(001 \wedge \bar{1}01)} \quad \text{or} \quad \tan(001 \wedge \bar{1}01) = \frac{\grave{c}\sin\beta}{\grave{a} - \grave{c}\,.\cos\beta}. \end{aligned}\right\} \tag{3}$$

These relations may be made more general by writing in the several cases—

in (1) $hk0$ for 110 and $\frac{k}{h}\grave{a}$ for $\grave{a}$; in (2) $0kl$ for 011 and $\frac{k}{l}\grave{c}$ for $\grave{c}$;

in (3) $h0l$ for 100 and $\frac{h}{l}\grave{c}$ for $\grave{c}$.

Also

$$\frac{\grave{c}}{\grave{a}} = \frac{\sin(001 \wedge 101)}{\sin(100 \wedge 101)} = \frac{\sin(001 \wedge \bar{1}01)}{\sin(100 \wedge \bar{1}01)},$$

and more generally

$$\frac{h}{\grave{a}} \cdot \frac{\grave{c}}{l} = \frac{\sin(001 \wedge h0l)}{\sin(100 \wedge h0l)} = \frac{\sin(001 \wedge \bar{h}0l)}{\sin(100 \wedge \bar{h}0l)}.$$

Note also that

$$\tan\phi = \grave{a} \quad \text{and} \quad \tan\zeta = \grave{c};$$

where ϕ is the angle (Fig. 327) between the zone-circles (001, 100) and (001, 110); also ζ the angle between (100, 001) and (100, 011).

All the above relations are important and should be thoroughly understood.

195. The problems which usually arise have as their object either the deducing of the axial elements, the angle β and the values of $\grave{a}$ and $\grave{c}$ in terms of $\grave{b}$ (= 1), from three measured angles, or the finding of any required interfacial angles from these elements or from the fundamental angles.

The simple relations of the preceding article connect the angular and axial elements, and beyond this all ordinary problems can be solved* either by the solution of spherical triangles on the sphere of projection, or by the aid of the cotangent (and tangent) relation.

It is to be noted, in the first place, that all great circles on the sphere of projection (Fig. 327) from 010 cut the zone circle 100, 001, $\bar{1}00$ at right angles, but those from 100 cut the zone circles 010, 001, $0\bar{1}0$ obliquely, as also those from 001 cutting the zone circle 100, 010, $\bar{1}00$.

196. Tangent and Cotangent Relations.—The simple *tangent relation* holds good for all zones from 010 to any pole on the zone circle 100, 001, $\bar{1}00$; in other words, for the prisms, clinodomes, and zones of pyramids in which the ratio of $h : l$ is constant (from 001 to $h0l$ or to $\bar{h}0l$). Thus it is still true, as in the orthorhombic system, that the tangents of the angles of the prisms 210, 110, 120, 130 from 100 are in the ratio of ½ : 1 : 2 : 3, or, more generally, that

---

* The general formulas, from which it is possible to calculate directly the angles between any face and the pinacoids, or the angle between any two faces whatever, are so complex as to be of little value.

$$\frac{\tan(100 \wedge hk0)}{\tan(100 \wedge 110)} = \frac{k}{h} \quad \text{or} \quad \frac{\tan(010 \wedge hk0)}{\tan(010 \wedge 110)} = \frac{h}{k}.$$

Also for the clinodomes the tangents of the angles of 012, 011, 021 from 001 are in the ratio of ½ : 1 : 2, etc. A similar relation holds for the tangents of the angles of pyramids in the zones mentioned, as 121, 111, 212, etc.

For zones other than those mentioned in the preceding article, as from 100 to a clinodome, or from 001 to a prism, the more general *cotangent formula* given in Art. 47 must be employed. This relation is simplified for certain common cases.

For any zone starting from 001, as the zone 001, 100, or 001, 110, or 001, 210, etc.; if two angles are known, viz., the angles between 001 and those two faces in the given zone which fall (1) in the zone 010, 101, and (2) in the prismatic zone 010, 100; then the angle between 001 and any other face in the given zone can be calculated.

Thus,

$$\begin{array}{llcl} & \text{Let } 001 \wedge 101 = PQ & \text{and} & 001 \wedge 100 = PR, \\ \text{or} & \text{“ } 001 \wedge 111 = PQ & \text{“} & 001 \wedge 110 = PR, \\ \text{or} & \text{“ } 001 \wedge 212 = PQ & \text{“} & 001 \wedge 210 = PR, \text{ etc.} \end{array}$$

Then for these, or any similar cases, the angle (PS) between 001 and any face in the given zone (as 201, or 221, or 421, etc., or in general *h*0*l*, *hhl*, etc.) is given by the equation

$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{l}{h}.$$

For the corresponding zones from 001 to $\bar{1}00$, to $\bar{1}10$, to $\bar{2}10$, etc., the expression has the same value; but here

$$\begin{array}{llll} & PQ = 001 \wedge \bar{1}01, & PR = 001 \wedge \bar{1}00, & PS = 001 \wedge \bar{h}0l, \\ \text{or} & 001 \wedge \bar{1}11, \text{ etc.}, & 001 \wedge \bar{1}10, \text{ etc.}, & 001 \wedge \bar{h}hl, \text{ etc.} \end{array}$$

If, however, 100 is the starting-point, and

$$\begin{array}{lll} & 100 \wedge 101 = PQ, & 100 \wedge 001 = PR, \\ \text{or} & 100 \wedge 111 = PQ, & 100 \wedge 011 = PR, \text{ etc.,} \end{array}$$

then the relation becomes

$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{h}{l}.$$

VI. TRICLINIC SYSTEM.

197. The TRICLINIC SYSTEM includes all the forms which are referred to three unequal axes with all their intersections oblique.

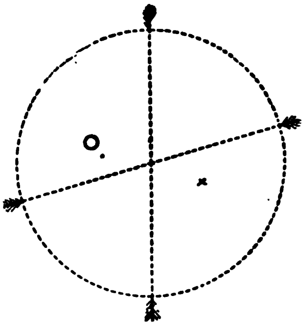
The axes are here designated as in the orthorhombic system, the letters used for the lateral axes $\breve{a}$, $\bar{b}$ (or $\bar{a}$, $\breve{b}$), having a short or long mark over them to indicate which is the shorter and which the longer axis. In the majority of cases, $\breve{a}$ is the brachy-axis and $\bar{b}$ the macro-axis. But this is not invariably true; thus with rhodonite the ratio of $\bar{a} : \breve{b} = 1{\cdot}073 : 1$. The vertical axis is always designated by $\dot{c}$. The angle between the axes *b* and $\dot{c}$ is called α, that between *a* and $\dot{c}$ is β, and that between *a* and *b* is γ (Fig. 333).

It is to be noted that there is no necessary relation between the values of α, β, and γ, any one may be greater or less than 90°; this is determined by the choice of the fundamental forms.

1. NORMAL GROUP (31). AXINITE TYPE.

198. Symmetry.—The normal group of the triclinic system is characterized by a center of symmetry, the point of intersection of the three axes, but there is no plane and no axis of symmetry.* This symmetry is shown in the accompanying spherical projection (Fig. 332).

332.



199. Forms.—Each form of the group includes two faces, parallel to one another and symmetrical with reference to the center of symmetry. This is true as well of the form with the general symbol (*hkl*) as of one of the special forms, as, for example, the *a*-pinacoid (100).

Hence, as shown in the following table, the four prismatic faces 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$ include two forms, namely, 110, $\bar{1}\bar{1}0$, and $\bar{1}10$, $1\bar{1}0$. The same is true of the domes. Further, any eight corresponding pyramidal faces, as, for example, 111, $\bar{1}11$, $\bar{1}\bar{1}1$, $1\bar{1}1$, $11\bar{1}$, $\bar{1}1\bar{1}$, $\bar{1}\bar{1}\bar{1}$, $1\bar{1}\bar{1}$ belong to four distinct forms, namely, 111, $\bar{1}\bar{1}\bar{1}$; $\bar{1}11$, $1\bar{1}\bar{1}$; $\bar{1}\bar{1}1$, $11\bar{1}$; $1\bar{1}1$, $\bar{1}1\bar{1}$, and similarly in general.

The various types of forms are given in the following table:

	Miller.		Naumann.
Macropinacoid or *a*-pinacoid	(100)	$\breve{a} : \infty\bar{b} : \infty\dot{c}$	$\infty P\bar{\infty}$ or $i\text{-}\bar{i}$, a
Brachypinacoid or *b*-pinacoid	(010)	$\infty\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P\breve{\infty}$ or $i\text{-}\breve{i}$, b
Base or *c*-pinacoid	(001)	$\infty\breve{a} : \infty\bar{b} : \dot{c}$	OP or O, c
Unit prism	(110)	$\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P'$ or I', m
	$(1\bar{1}0)$	$\breve{a} : -\bar{b} : \infty\dot{c}$	$\infty {'P}$ or $'I$, M
Macroprisms $h > k$	$(hk0)$	$\breve{a} : n\bar{b} : \infty\dot{c}$	$\infty P'\bar{n}$ or $i\text{-}\bar{n}'$
	$(h\bar{k}0)$	$\breve{a} : -n\bar{b} : \infty\dot{c}$	$\infty {'P}\bar{n}$ or $'i\text{-}\bar{n}$
Brachyprisms $h < k$	$(hk0)$	$n\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P\breve{n}$ or $i\text{-}\breve{n}$
	$(h\bar{k}0)$	$n\breve{a} : \bar{b} : \infty\dot{c}$	$\infty P\breve{n}$ or $i\text{-}\breve{n}$
Macrodomes	$(h0l)$	$\breve{a} : \infty\bar{b} : m\dot{c}$	$m'P'\bar{\infty}$ or $'m\text{-}\bar{i}'$
	$(\bar{h}0l)$	$-\breve{a} : \infty\bar{b} : m\dot{c}$	$m_{,}P_{,}\infty$ or $_{,}m\text{-}\bar{i}'$
Brachydomes	$(0kl)$	$\infty\breve{a} : \bar{b} : m\dot{c}$	$mP\infty'$ or $m\text{-}\breve{i}$
	$(0\bar{k}l)$	$\infty\breve{a} : -\bar{b} : m\dot{c}$	$'mP\infty$ or $m\text{-}\breve{i}$
Unit pyramids	(hhl)	$a : b : mc$	mP' or m'
	$(\bar{h}hl)$	$-a : b : mc$	$m_{,}P$ or $_{,}m$
	$(\bar{h}\bar{h}l)$	$-a : -b : mc$	$mP_{,}$ or $m_{,}$
	$(h\bar{h}l)$	$a : -b : mc$	$m'P$ or $'m$
Macropyramids† $h > k$	(hkl)	$\breve{a} : n\bar{b} : m\dot{c}$	$mP'\bar{n}$ or $m\text{-}\bar{n}'$
	$(\bar{h}kl)$	$-\breve{a} : n\bar{b} : m\dot{c}$	$m_{,}P\bar{n}$ or $_{,}m\text{-}\bar{n}$
	$(\bar{h}\bar{k}l)$	$-\breve{a} : -n\bar{b} : m\dot{c}$	$mP_{,}\bar{n}$ or $m\text{-}\bar{n}_{,}$
	$(h\bar{k}l)$	$\breve{a} : -n\bar{b} : m\dot{c}$	$m_{,}P\bar{n}$ or $'m\text{-}\bar{n}$

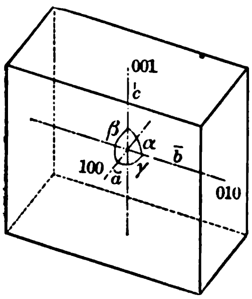
---

* On the other method of viewing the symmetry here described, see Art. 17, p. 10.

† In the above table it is assumed that the axial ratio is $\breve{a} : \bar{b} : \dot{c}$. If it were $\bar{a} : \breve{b} : \dot{c}$, the names brachy- and macro- would be exchanged, and also the long and short marks in the Naumann symbols. The use of accents to distinguish prisms, domes, and pyramids according to their position is to be noted.

Brachypyramids $h < k$	(hkl)	$n\breve{a} : \bar{b} : m\dot{c}$	$mP'\breve{n}$ or $m\text{-}\breve{n}'$
	$(\bar{h}kl)$	$-n\breve{a} : \bar{b} : m\dot{c}$	$m_{,}P\breve{n}$ or ${}_{,}m\text{-}\breve{n}$
	$(\bar{h}\bar{k}l)$	$- : n\breve{a} : -\bar{b} : m\dot{c}$	$mP_{,}\breve{n}$ or $m\text{-}\breve{n}_{,}$
	$(h\bar{k}l)$	$n\breve{a} : -\bar{b} : m\dot{c}$	$m'P'\breve{n}$ or $'m\text{-}\breve{n}$

333.



200. The explanations given under the two preceding systems make it unnecessary to discuss in detail the various forms individually, except as illustrated in the case of crystals belonging to certain typical triclinic species.

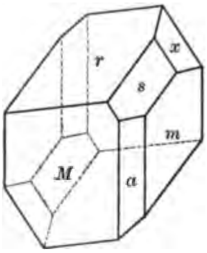
It may be mentioned, however, that Fig. 333 shows the *diametral prism*, which is bounded by three sets of unlike faces, the pinacoids *a*, *b*, and *c*. This is the analogue of the cube of the isometric system, but here the like faces, edges, and solid angles include only a given face, edge and angle, and that opposite to it.

201. Illustrations.—A typical triclinic crystal is shown in Fig. 334 of axinite, already introduced. Here *a* (100) is the macropinacoid; *m* (110) and *M* (1$\bar{1}$0) the two unit prisms; *s* (201) a macrodome, and *x* (111) and *r* (1$\bar{1}$1) two unit pyramids. The axial ratio is as follows:

$$\breve{a} : \bar{b} : \dot{c} = 0{\cdot}49 : 1 : 0{\cdot}48,\ \alpha = 82^\circ\ 54',\ \beta = 91^\circ\ 52',\ \gamma = 131^\circ\ 32'.$$

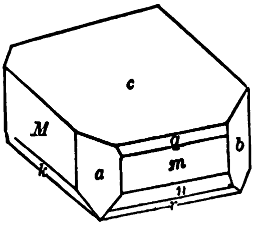
Figs. 335, 336 show two crystals of rhodonite, a species which is allied to pyroxene, and which approximates to it in angle and habit. Here the faces

334.

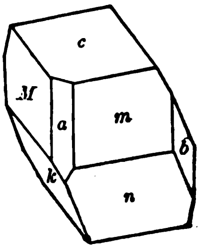


Axinite.

335.



336.

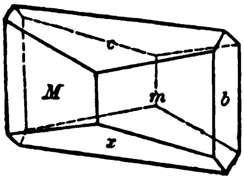


Rhodonite.

are: Pinacoids *a* (100), *b* (010), *c* (001); prisms *m* (110), *M* (1$\bar{1}$0); pyramids *q* (221), *k* ($\bar{2}$21), *n* ($\bar{2}\bar{2}$1), *r* ($\bar{1}\bar{1}$1).

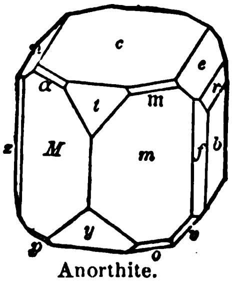
Further illustrations are given by Fig. 337 of albite and Fig. 338 of anorthite. The symbols of the faces, besides the pinacoids and the unit prisms, are as follows: Fig. 337, *x* ($\bar{1}$01); Fig. 338, prisms *f* (130), *z* (1$\bar{3}$0); domes *t* (207), *y* ($\bar{2}$01), *e* (021), *r* (061), *n* (0$\bar{2}$1); pyramids m (111), *α* (1$\bar{1}$1), *o* ($\bar{1}\bar{1}$1), *p* ($\bar{2}$11). In Fig. 338 of anorthite the similarity of the crystal to one of orthoclase is evident on slight examination (cf. Figs. 319, 320), and careful study with the measurement of angles shows that the correspondence is very

337.



Albite.

338.

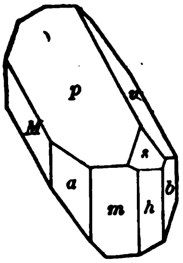


Anorthite.

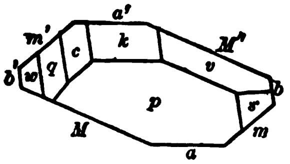
close. Hence in this case the choice of the fundamental planes is readily made.

Fig. 339 represents a crystal (artificial) of blue vitriol, the mineral chalcanthite; Fig. 339*a* gives a projection on a zone normal to the prisms, and Fig. 340 a spherical projection. The last figure also shows the symbols of the different faces.

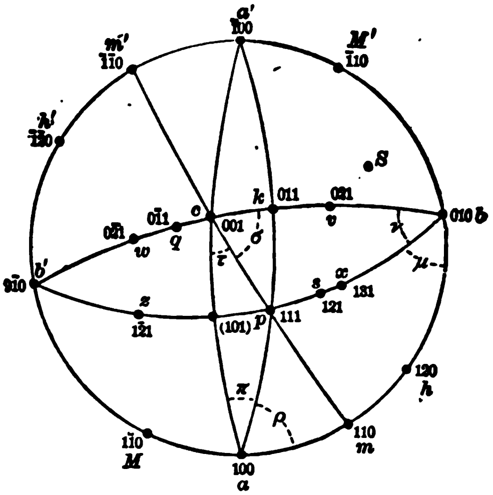
339.



339*a*.



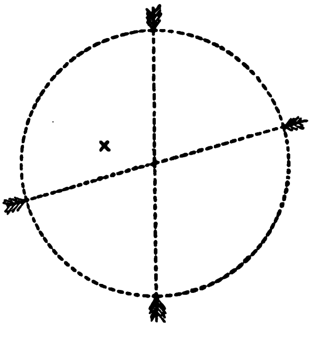
340.



2. ASYMMETRIC GROUP (32).

202. Besides the normal group of the triclinic system there is another possible group, possessing symmetry neither with respect to a plane, axis nor center; in it a given form has *one face* only. This group, the *asymmetric* class of Groth, finds examples among a number of artificial salts. One of these is calcium thiosulphate ($CaS_2O_3 . 6H_2O$); as yet no mineral species is known to be included here. This is the most general of all the thirty-two types of forms classified according to their symmetry and comes first, therefore, if the groups are arranged in order according to the degree of symmetry characterizing them. This group is one of those whose crystals may show circular polarization. This is true of eleven of the groups which have been described in the preceding pages.

341.



Mathematical Relations of the Triclinic System.

203. Choice of Axes.—It is obvious, from what has been said as to the symmetry of this system, that *any* three faces of a triclinic crystal may be chosen as the pinacoids, or the faces which fix the position of the axial planes and the directions of the axes; moreover, there is a like liberty in the choice of the unit prisms, domes or pyramids which further fix the lengths of the axes.

When the crystal in hand is allied in form or composition to other species whether of the same or different systems, this fact simplifies the problem and makes the choice of the fundamental forms easy. This is well illustrated, as already noted, by the triclinic feldspars (e.g., albite and anorthite, Figs. 387, 388) which are near in angle to the allied monoclinic species orthoclase. Rhodonite (Figs. 385, 386), the triclinic member of the pyroxene group, is another good example.

In other cases, where no such relationship exists, and where varied habit makes different orientations plausible, there is but little to guide the choice. This is illustrated in the case of axinite (Fig. 384), where at least ten distinct positions have been assumed by different authors.

204. Axial and Angular Elements.—The *axial elements* of a triclinic crystal are: (1) the axial ratio, which expresses the lengths of the axes a and $\grave{c}$ in terms of the third axis, $\bar{b}$; and (2) the angles between the axes α, β, γ (Fig. 333). There are here five quantities to be determined which obviously require the measurement of five independent angles between the faces.

The *angular elements* are usually taken as the angles between the pinacoids and, in addition, those between each pinacoid and the unit face lying in the zone of the other pinacoids; that is,

ab, 100 ∧ 010, *ac*, 100 ∧ 001, *bc*, 010 ∧ 001;

also

am 100 ∧ 110, 001 ∧ 101, 001 ∧ 011;

or, instead, any one or all of these,

aM, 100 ∧ $1\bar{1}0$, 001 ∧ $\bar{1}01$, 001 ∧ $0\bar{1}1$.

Of these six angles taken, one is determined when the others are known.

205. The mathematical relations existing between the axial angles and axial ratio, on the one hand, and the angles between the faces on the other, admit of being drawn out with great completeness, but they are necessarily complex and in general have little practical value. In fact, most of the problems likely to arise can be solved by means of the triangles of the spherical projection, together with the cotangent formula connecting four planes in the same zone (Art. 47, p. 31); this will often be laborious and may require some ingenuity, but in general involves no serious difficulty. In connection with the use of the cotangent formula, it is to be noted that in certain commonly occurring cases its form is much simplified; some of these have already been explained under the monoclinic system (Art. 196). The formulas given there are of course equally applicable here.

206. The first problem may be to find the axial elements from measured angles. Since these elements include five unknown quantities, viz., the three axial angles α, β, γ and the lengths of the axes a and $\grave{c}$ in terms of b, five measured angles are required, as already stated.

These angles, by use of three or more spherical triangles, will serve to give the angles (see Fig. 340) π, ρ, μ, ν, r, σ (or the corresponding angles π', ρ', etc., in the adjacent quadrants). The ratio of the sines of each pair of these angles fixes the ratios of the corresponding axes (see below). The full axial ratio may be obtained from any two pairs and the third ratio serves as a check upon the results given by the other two.

The simple formulas required are:

$$\frac{\sin r}{\sin \sigma} = \frac{\sin r'}{\sin \sigma'} = \frac{a}{b}, \quad \frac{\sin \nu}{\sin \mu} = \frac{\sin \nu'}{\sin \mu'} = \frac{\grave{c}}{a}, \quad \frac{\sin \pi}{\sin \rho} = \frac{\sin \pi'}{\sin \rho'} = \frac{\grave{c}}{b}.$$

If the corresponding angles for the general case are given (not those of the unit zones , th relations are similar. That is, if for the face *hkl* the corresponding angles be represente by r_0, σ_0, etc., where r_0, σ_0 are the angles between the zone circles 100, 001 and 100, 010 respectively and the zone circle 001, *hk*0 (and similarly for r_0, σ_0 in the adjace quadrant, also similarly ν_0, μ_0, etc.), these relations may be expressed in the general form

$$\frac{\sin r_0}{\sin \sigma_0} = \frac{\sin r_0'}{\sin \sigma_0'} = \frac{a}{\frac{h}{k}b} = \frac{k}{h} \cdot \frac{a}{b},$$

and similarly for $\dfrac{\sin \nu_0}{\sin \mu_0}$, etc.

Thus for the face 321 the formulas become

$$\frac{\sin \tau_0}{\sin \sigma_0} = \frac{a}{\frac{3}{2}b} = \frac{2}{3}\frac{a}{b}, \quad \frac{\sin \nu_0}{\sin \mu_0} = \frac{3c}{a}, \quad \frac{\sin \pi_0}{\sin \rho_0} = \frac{2c}{b}.$$

It is also to be noted that

$$\alpha = 180° - A, \qquad \beta = 180° - B, \qquad \gamma = 180° - C,$$

where A, B, C are the angles in the pinacoidal spherical triangle 100·010·001 at these poles respectively. That is,

$$A = \pi + \rho = \pi_0 + \rho_0 = (180° - \alpha);$$

$$B = \nu + \mu = \nu_0 + \mu_0 = (180° - \beta);$$

$$C = \tau + \sigma = \tau_0 + \sigma_0 = (180° - \gamma).$$

Also

$$180° - A = \pi' + \rho' = \pi_0' + \rho_0' = \alpha.$$

Hence, having given, by measurement or calculation, the angles between the faces *ab* (100 ∧ 010), *ac* (100 ∧ 001) and *bc* (010 ∧ 001), which are the sides of this triangle, the angles A, B, C are calculated and their supplements are the axial angles α, β, γ respectively.

Still another series of equations are those below, which give the relations of the angles μ, ν, ρ, etc., to the axes and axial angles. By means of them, with the sine formulas given above, the angular elements (and other angles) can be calculated from the axial elements.

$$\tan \mu = \frac{a \sin \beta}{c + a \cos \beta}; \quad \tan \nu = \frac{c \sin \beta}{a + c \cos \beta}.$$

$$\tan \rho = \frac{b \sin \alpha}{c + b \cos \alpha}; \quad \tan \pi = \frac{c \sin \alpha}{b + c \cos \alpha}.$$

$$\tan \tau = \frac{a \sin \gamma}{b + a \cos \gamma}; \quad \tan \sigma = \frac{b \sin \gamma}{a + b \cos \gamma}.$$

These equations apply when $\mu + \nu$, etc., is less than 90°; if their sum is greater than 90° the sign in the denominator is negative.

207. The following equations are also often useful; they give the relations between the angles α, β, γ, and the angles μ, ν, etc., already defined.

$$\tan \alpha = \frac{2 \sin \rho \sin \rho'}{\sin (\rho - \rho')} = \frac{2 \sin \pi \sin \pi'}{\sin (\pi - \pi')}.$$

$$\tan \beta = \frac{2 \sin \mu \sin \mu'}{\sin (\mu - \mu')} = \frac{2 \sin \nu \sin \nu'}{\sin (\nu - \nu')}.$$

$$\tan \gamma = \frac{2 \sin \tau \sin \tau'}{\sin (\tau - \tau')} = \frac{2 \sin \sigma \sin \sigma'}{\sin (\sigma - \sigma')}.$$

Also,

$$\alpha + \pi + \rho = \beta + \mu + \nu = \gamma + \tau + \sigma = 180°.$$

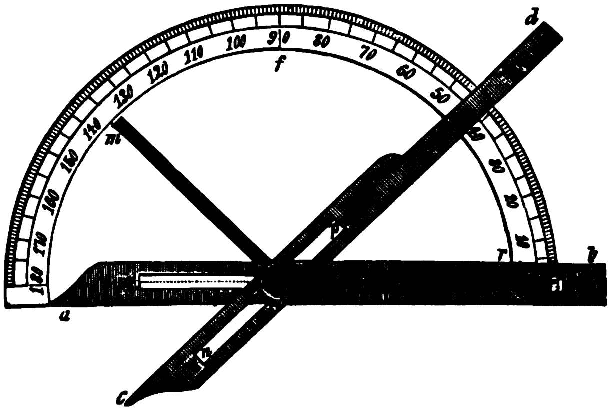
The calculation, from the angular elements or from the assumed fundamental measured angles, either (1) of the angular position of any face whose symbol is given, or (2) of the symbol of an unknown face for which measured angles are at hand, requires no further explanation. The cotangent formula is all that is needed in a single zone, and the solution of spherical triangles on the projection (with the use of the sine formulas) will suffice in addition in all ordinary cases.

MEASUREMENT OF THE ANGLES OF CRYSTALS.

208. Hand-Goniometers.—The interfacial angles of crystals are measured by means of instruments which are called *goniometers*.

The simplest form is the hand-goniometer, represented in Fig. 342. It consists of an arc, graduated to half-degrees or finer, and two movable arms. In the instrument figured, one of the arms, *ab*, has the motion forward and backward by means of slits *gh*, *ik*; the other arm, *cd*, has also a similar slit, and in addition it turns around the center of the arc as an axis. The faces whose inclination is to be measured are applied between the arms *ao*, *co*, and the latter adjusted so that they and the surfaces are in close contact; further, the arms must be exactly at right angles to the intersection-edge. This adjustment must be made with care, and when the instrument is held up to the light none must pass through between the arm and the face. The number of degrees read off on the arc between *k* and the left edge of *d* (this edge being in the line of the center, *o*, of the arc) is the angle required. The motion to and fro by means of the slits is for the sake of convenience in measuring small or embedded crystals. In a better form of the instrument the arms are wholly separated from the arc; and the arc is a delicately graduated circle to which the arms are adjusted after the measurement.

342.

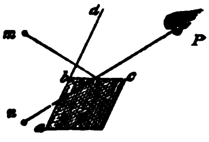


The hand-goniometer is useful in the case of large crystals and those whose faces are not well polished; the measurements with it, however, are seldom accurate within a quarter of a degree. In the finest specimens of crystals, where the faces are smooth and lustrous, results far more accurate may be obtained by means of a different instrument, called the reflecting goniometer.

209. Reflecting Goniometer.—This instrument, devised by Wollaston (1809), has been much improved in its various parts since his time by Mitscherlich and others. The principle on which it is constructed may be understood by reference to the following figure (Fig. 343), which represents the section of a crystal, whose angle, *abc*, between the faces *ab*, *bc*, is required.

The eye at *P*, looking at the face of the crystal, *bc*, observes a reflected image of *m*, in the direction of *Pn*. The crystal may now be so changed in its position that the same image is seen reflected by the next face and in the same direction, *Pn*. To effect this, the crystal must be turned around, until *abd* has the present direction of *bc*. The angle *dbc* measures, therefore, the number of degrees through which the crystal must be turned; it may be measured by attaching the crystal to a graduated circle, which turns with the crystal. This angle is the supplement of the interior angle between the two faces, or in other words is the *normal angle*, or angle between the two poles (see Art. 41, p. 28). The reflecting goniometer hence gives directly the angle needed on the system of Miller here followed.

343.



Many different forms of reflecting goniometer of simple type are in use. The accompanying figure (Fig. 344) will suffice to make clear the general character of the instrument, as well as to exhibit some of the refinements added for the sake of greater exactness of measurement.

The circle, *C*, is graduated, in this case, to twenty minutes, and by means of the vernier at *v* the readings may be made to minutes and half-minutes. The crystal is attached by means of wax to the little plate at *k*; this may be removed for convenience, but in its final position it is, as here, at the extremity of the axis of the instrument. This axis is moved by means of the wheel, *n*; the graduated circle is moved by the wheel, *m*. These motions are so arranged that the motion of *n* is independent, its axis being within the other, while on the other hand the revolution of *m* moves both the circle and the axis to which the crystal is attached. This arrangement is essential for convenience in the use of the instrument, as will be seen in the course of the following explanation. The screws, *c*, *d*, are for the adjustment of the crystal, and the slides, *a*, *b*, serve to center it.

The method of procedure is briefly as follows: The crystal is attached by means of suitable wax at *k*, and adjusted by the hand so that the direction of the combination-edge of the two faces to be measured coincides with the axis of the instrument; the wheel, *n*, is turned until an object (*e.g.*, a window-bar) reflected in one face is seen to coincide with another object not reflected (*e.g.*, a chalk-line on the floor); the position of the graduated circle is observed, and then both crystal and circle revolved together by means of the wheel, *m*, till the same reflected object now seen in the *second* face again coincides with the fixed object (that is, the chalk-line); the angle through which the circle has been moved, as read off by means of the vernier, is the normal angle between the two faces.

In order to secure accuracy, several conditions must be fulfilled, of which the following are the most important:

1. The position of the eye of the observer must remain perfectly stationary.

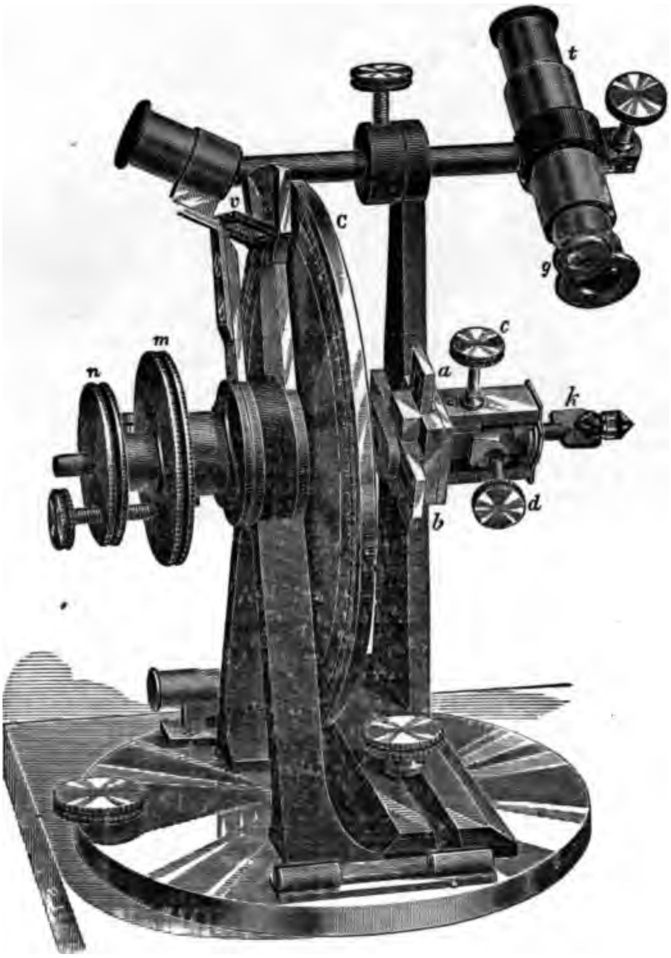
2. The object reflected and that with which it is brought in coincidence should be at an equal distance from the instrument, and this distance should not be too small.

3. The crystal must be accurately *adjusted;* this condition is satisfied when the line seen reflected in the case of each face and that seen directly with which it is in coincidence are horizontal and parallel. It can be true only when the intersection-edge of the two faces measured is exactly in the *direction*

of the axis of the instrument, and perpendicular to the plane of the circle. The adjustment is accomplished roughly by the hand and accurately by the screws *c* and *d*.

4. The crystal must be ***centered*** as nearly as possible, or, in other words, the same intersection-edge must ***coincide*** with a line drawn through the revolving axis. This condition will be seen to be distinct from the preceding, which required only that the two *directions* should be the same. The error arising when this condition is not satisfied diminishes as the object reflected is removed farther from the instrument, and becomes zero if the object is at an infinite distance. In the centering of the crystal the slides *a* and *b* are employed.

344.



The first and second conditions are both satisfactorily fulfilled by the use of a telescope, as *t* (Fig. 344), with slight magnifying power. This is arranged for parallel light, and provided with a hair-cross in its focus. It admits also of some adjustments, as seen in the figure, but when used it must be directed exactly toward the axis of the goniometer. This telescope has also a little magnifying-glass (*g*) attached to it, which allows of the crystal itself being seen when mounted at *k*. This latter is used for the first adjustments of the crystal, and then slipped aside, when some distant object which has been selected must be seen in the field of the telescope as reflected, first by the one face and then by the other as the wheel *n* is revolved. When the final adjustments have been made so that in each case the object coincides with the center of the hair-cross of the telescope, and when further the edge to be measured has been centered, the crystal is ready for measurement.

This telescope, obviously, can be used only when the face is smooth and large enough to give distinct and brilliant reflections.* In many cases sufficient accuracy is obtained without it by the use of a window-bar and a white chalk-line on the floor below for the two objects; the instrument in this case is placed at the opposite end of the room, with its axis parallel to the window; the eye is brought very close to the crystal and held motionless during the measurement.

The best instruments are provided with two telescopes. The second stands opposite the telescope, *t* (see figure), the centers of both telescopes being in the same plane perpendicular to the axis of the instrument. This second telescope has also a hair-cross in the focus, and this when illuminated by a brilliant gas-burner (the rest of the instrument being protected from the light by a screen) will be reflected in the successive faces of the crystal. The reflected cross is brought in coincidence with the cross in the first telescope, first for one and then for the other face. As the lines are delicate, and as exact coincidence can take place only after perfect adjustment, it is evident that a high degree of accuracy is possible. Still more than before, however, are well-polished crystals required, so that in many cases the use of the ordinary double telescopes is impossible. Very often the hair-cross of the second telescope may be advantageously replaced by a bright line or cross, the light shining through a cross cut in tin-foil (Schrauf), or as given by the analogous Websky signal. This light-signal is visible in the first telescope even when the planes are extremely minute, or, on the other hand, somewhat rough and uneven; even if the image is not perfectly distinct, it may be sufficiently so to admit of fairly good measurements (*e.g.*, within two or three minutes).

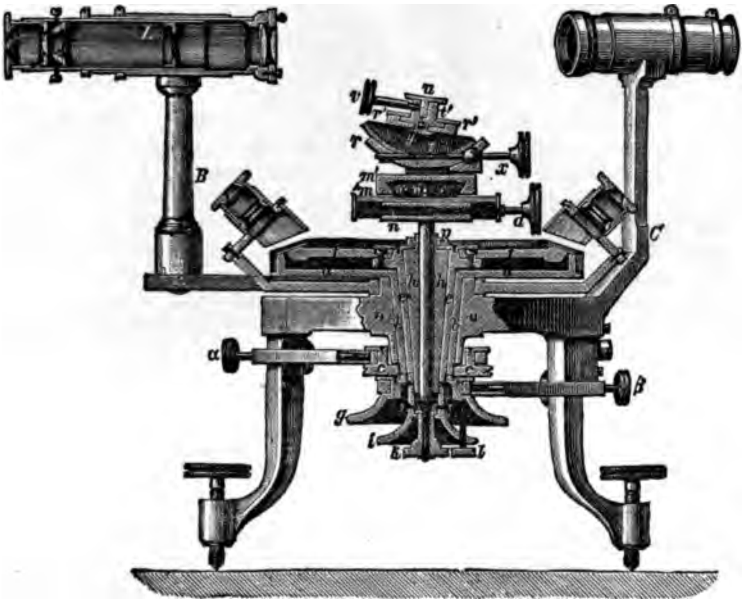
210. Horizontal Goniometer.—A form of reflecting goniometer well adapted for accurate measurements is shown in Fig. 345. It is made on the Babinet type, with a *horizontal* graduated circle; the instruments of the Mitscherlich type, just described, having a vertical circle. The horizontal circle has many advantages, especially when it is desired to measure the angles of large crystals or those which are attached to the rock. This particular form of instrument here figured* is made by R. Fuess in Berlin.

---

* When planes are rough and destitute of luster the angles can often best be obtained by use of a candle-flame, the diffuse reflection of which in the given face takes the place of more distinct images. For embedded crystals, and often in other cases, measurements may be very advantageously made from impressions in some material, like sealing-wax. Angles thus obtained ought to be accurate within one degree, or even less, and suffice for many purposes. It is sometimes of advantage to attach to the planes to be measured, when quite rough, fragments of thin glass, from which reflections can be obtained; this must, however, be done with care, to avoid considerable error. Occasionally dusting the surface with graphite makes a "shimmer" measurement with the candle-flame possible, or, again, covering it with a thin film of gum arabic.

The instrument stands on a tripod with leveling screws. The central axis, *o*, has within it a hollow axis, *b*, with which turns the plate, *d*, carrying the verniers and also the observing telescope, the upright support of which is shown at *B*. Within *b* is a second hollow axis, *e*, which carries the graduated circle, *f*, above, and which is turned by the screw-head, *g*; the tangent screw, *α*, serves as a fine adjustment for the observing telescope, *B*, the screw, *c*, being for this purpose raised so as to bind *b* and *e* together. The tangent screw, *β*, is a fine adjustment for the graduated circle. Again, within *e* is the third axis, *h*, turned by the screw-head, *i*, and within *h* is the central rod, which carries the support for the crystal, with the adjusting and centering contrivances mentioned below. This rod can be raised or lowered by the screw, *k*, so as to bring the crystal to the proper height—that is, up to the axis of the telescope; when this has been accomplished, the clamp at *p*, turned by a set-key, binds *s* to the axis, *h*. The movement of *h* can take place independently of *g*, but after the crystal is ready for measurement these two axes are bound together by the set-screw, *l*. The signal telescope is supported at *C*, firmly attached to one of the legs of the tripod. The crystal is mounted on the plate, *u*, with wax, the plate is clamped by the screw, *v*. The *centering* apparatus consists of two slides at right angles to each other (one of these is shown in the figure) and the screw, *a*, which works it; the end of the other corresponding screw is seen at *a'*. The *adjusting* arrangement consists of two cylindrical sections, one of them, *r*, shown in the figure, the other is at *r'*; the cylinders have a common center.

345.



---

* The figure here used is from the catalogue of Fuess.

The circle is graduated to degrees and quarter degrees, and the vernier gives the readings to 30″, but by estimate they can be obtained to 10″. The signals provided are four in number, each in its own tube, to be inserted behind the collimator lens; these are: (1) the ordinary telescope with the hair-cross, to be used in the case of the most perfect faces; (2) the commonly used signal, proposed by Websky, consisting of two small opaque circles, whose distance apart can be adjusted by a screw between them; the light passing between these circles enters the tube in a form resembling a double concave lens; also (3) an adjustable slit; and, finally, (4) a tube with a single round opening, very small. There are four observing telescopes of different angular breadth of field and magnifying power, and hence suitable for faces varying in size and in degree of polish.

The methods to be employed, both in making the preliminary adjustments required by every instrument before it can be used and in the actual measurement of the angles of crystals, have been described by Websky [*] with a fullness and clearness which leave nothing to be desired, and reference must be here made to his memoir.

211. Theodolite-Goniometer.—A form of goniometer [†] having many practical advantages has two independent circles; it can be used in a manner analogous to that of the ordinary theodolite, as will appear below. Instruments of this type have been devised independently by Fedorow, Czapski, and Goldschmidt. In addition to the usual graduated horizontal circle of Fig. 345, and the two accompanying telescopes, a second graduated circle is added which revolves in a plane at right angles to the first; to the latter the crystal to be measured is attached, with the addition of suitable adjusting and centering contrivances.

By this instrument, instead of the interfacial angles being measured directly, the position of each face is determined independently of others by the measurement of its angular co-ordinates. These co-ordinates are the angles (ϕ and ρ of Goldschmidt) measured, respectively, in the vertical and horizontal circles from an assumed pole and meridian, which are fixed, in most cases, by the symmetry of the crystal. In practice the crystal is usually so mounted that the prismatic zone is perpendicular to the vertical circle and a pinacoid in this zone is the zero point. For example, with an orthorhombic crystal, for the face 111, the angle ϕ is equal to $010 \wedge 110$ and ρ to $001 \wedge 111$ for the given species. Goldschmidt has shown that this instrument is directly applicable to the system of indices and methods of calculation and projection adopted by him, which admit of the deducing of the elements and symbols of a given crystal with a minimum of labor and calculation.[‡] Fedorow has also shown that this instrument, with the addition of the appliances devised by him, can be most conveniently used in the crystallographic and optical study of crystals.

---

[*] See Websky, Zs. Kryst., **3**, 241, 1879; **4**, 545, 1880; also Liebisch, Bericht über die wissenschaftlichen Instrumente auf der Berliner Gewerbeausstellung im Jahre 1879, pp. 330–332.

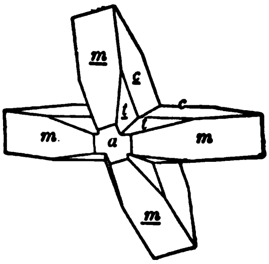
[†] Fedorow, Universal or Theodolit-Goniometer, Zs. Kryst., **21**, 574, 1893; **22**, 229, 1893; Czapski, Zeitschr. f. Instrumentenkunde, 1, 1893; Goldschmidt, Zs. Kryst., **21**, 210, 1892; **24**, 610, 1895; **25**, 321, 538, 1896. On the method of Goldschmidt, see Palache, Am. J. Sc., **2**, 279, 1896. A simplified form of the theodolite-goniometer is described by Stöber, Zs. Kryst., **29**, 25, 1897.

[‡] Goldschmidt's latest contribution to this subject is his work, Krystallographische Winkeltabellen (432 pp., Berlin, 1897). This gives the angles required by his system for all known species. See also Zs. Kryst., **29**, 361, 1898.

COMPOUND OR TWIN CRYSTALS.

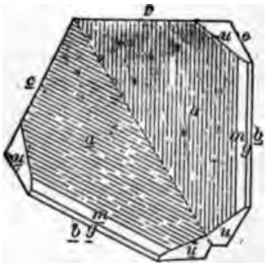
212. Twin Crystals.—Twin crystals are those in which one or more parts regularly arranged are in reverse position with reference to the other part or parts. They often appear externally to consist of two or more crystals symmetrically united, and sometimes have the form of a cross or star. They also exhibit the composition in the reversed arrangement of part of the faces, in the striæ of the surface, and in re-entering angles; in certain cases the compound structure can only be surely detected by an examination in polarized light. The above figures (Figs. 346–348) are examples of typical kinds of twin crystals, and many others are given on the pages following.

346.



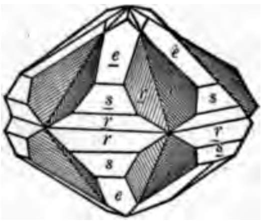
Thenardite.

347.



Columbite.

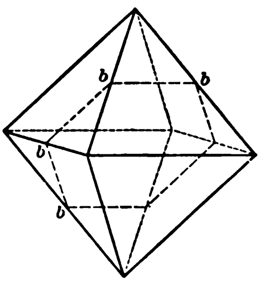
348.



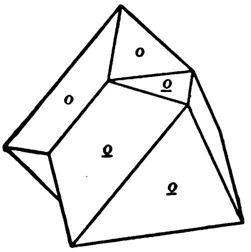
Chal azite.

To illustrate the relation of the parts in a twin crystal, Figs. 349, 350 are given. Fig. 349 shows a regular octahedron divided into two halves by a plane parallel to an octahedal face. If now the lower half be supposed to be revolved 180° about an axis normal to this plane, the twinned octahedron of Fig. 350 results. This is a common type of twin in the isometric system, and the method here employed to describe the position of the parts of the crystal to one another is applicable to nearly all twins.

349.



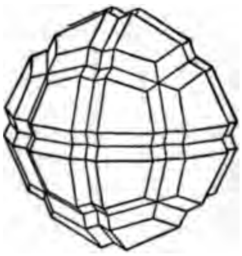
350.



213. It is important to understand that crystals, or parts of crystals, so grouped as to occupy parallel positions with reference to each other—that is, those whose similar faces are parallel—are not called twins; the term is applied only where the crystals or parts of them are united in their reversed position in accordance with some deducible mathematical law. Thus Fig. 351, which represents a cluster of partial crystals of analcite, is said to be a case of *parallel grouping* simply (see Art. **231**); but Fig. 369 illustrates twinning, and this is true of Fig. 378 also. Since though in these cases the axes remain parallel the similar faces (and planes of symmetry) are reversed in position.

214. Twinning-axis.—The relative position of the parts of a twinned crystal can be best described as just explained, by reference to that line or axis called the *twinning-axis*, a revolution of 180° about which would serve to bring the twinned part parallel to the other, or in other words, which would cause one of the parallel parts to take a twinned position relatively to the other.

351.



Analcite.

The twinning-axis is always a possible crystalline line—that is, either a crystallographic axis or the normal to some possible face on the crystal, usually one of the common fundamental forms.

It is not to be supposed that ordinary twins have actually been formed by such a revolution of the parts of crystals, for all twins (except those of secondary origin, see Art. 221) are the result of regular molecular growth or enlargement, like that of the simple crystal. This reference to a *revolution*, and an *axis of revolution*, is only a convenient means of describing the forms.

In certain rare cases, particularly of certain pseudo-hexagonal species, a revolution of 60° or 120° about a normal to the base has been assumed to explain the complex group observed.

215. Twinning-plane.—The plane normal to the axis of revolution is called the *twinning-plane*. The axis and plane of twinning bear the same relation to both individuals in their reversed position; consequently, in the majority of cases the twinned crystals are symmetrical with reference to the twinning-plane.

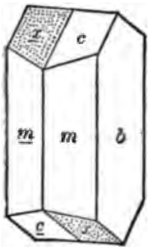
The twinning-plane is, with rare exceptions, parallel to a possible occurring face on the given species, and usually one of the more frequent or fundamental forms. The exceptions occur only in the triclinic and monoclinic systems, where the twinning-axis is sometimes one of the oblique crystallographic axes, and then the plane of twinning normal to it is obviously not necessarily a crystallographic plane; this is conspicuously true in albite.

216. Composition-plane.—The plane by which the reversed crystals are united is the *composition-plane*. This and the twinning-plane very commonly coincide; this is true of the simple example given above (Fig. 350), where the plane about which the revolution may be conceived to take place (normal to the twinning-axis) and the plane by which the semi-individuals are united are identical. When not coinciding, the two planes are generally at right angles to each other—that is, the composition-plane is parallel to the axis of revolution. Examples of this are given beyond. Still again, where the crystals are not regularly developed, and where they interpenetrate, the contact surface may be interrupted, or may be exceedingly irregular. In such cases the axis and plane of twinning have, as always, a definite position, but the composition-plane loses its significance.

Thus in quartz twins the interpenetrating parts have often no rectilinear boundary, but mingle in the most irregular manner throughout the mass, showing this composite irregularity by abrupt variations in the character of the surfaces. This irregular internal structure, found in many quartz crystals, even the common kinds, is well brought out by means of polarized light; also by etching with hydrofluoric acid.

The composition-plane has sometimes a more definite signification than the twinning-plane. This is due to the fact that in many cases, whereas the former is fixed, the twinning-axis (and twinning-plane) may be exchanged for another line (and plane) at right angles to each, respectively; since a revolution about the second axis will also satisfy the conditions of producing the required form. An example of this is furnished by Fig. 352, of orthoclase; the composition-plane is here fixed—namely, parallel to the crystal face, *b* (010). But the axis of revolution may be either (1) parallel to this face and normal to *a* (100), which is then consequently the twinning-plane, though the axis does not coincide with the crystallographic axis; or (2) the twinning-axis may be taken as coinciding with the vertical axis, and then the twinning-plane normal to it is not a crystallographic face. In other simpler cases, also, the same principle holds good, generally in consequence of the possible mutual interchange of the planes of twinning and composition. In most cases the true twinning-plane is evident, since it is parallel to some face on the crystal of simple mathematical ratio.

352.



217. An interesting example of the possible choice between two twinning-axes at right angles to each other is furnished by the species staurolite. Fig. 409 shows a prismatic twin from Fannin Co., Ga. The measured angle for *bb* was 70° 30′. The twinning-axis deduced from this may be normal to the face (230), which would then be the twinning-plane. Or, instead of this axis, its complementary axis at right angles to it may be taken, which would equally well produce the observed form. Now in this species it happens that the faces, 1$\bar{3}$0 and 230 (over 100), are almost exactly at right angles with each other, and, according to the latter supposition, 130 becomes the twinning-plane, and the axis of revolution is normal to it. Hence, either 230 or 130 may be the twinning-plane, either supposition agreeing closely with the measured angle (which could not be obtained with great accuracy). The former method of twinning (tw. pl. 230) conforms to the other twins observed on the species, and hence it may be accepted. What is true in this case, however, is not always true, for it will seldom happen that of the two complementary axes each is so nearly normal to a face of the crystal. In most cases one of the two axes conforms to the law in being a normal to a possible face, and the other does not, and hence there is no doubt as to which is the true twinning-axis.

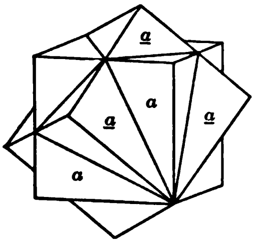
Another interesting case is that furnished by columbite. The common twins of the species are similar to Fig. 347, p. 118, and have *e* (021) as the twinning-plane; but twins also occur like Fig. 404, p. 128, where the twinning-plane is *q* (023). The two faces, 021 and 0$\bar{2}$3, are nearly at right angles to each other, but the measured angles are in this case sufficiently exact to prove that the two kinds cannot be referred to one and the same law.

218. Contact- and Penetration-twins.—In *contact-twins*, when normally formed, the two halves are simply connate, being united to each other by the composition-plane; they are illustrated by Figs. 347, 350, etc. In actually occurring crystals the two parts are seldom symmetrical, as demanded by theory, but one may preponderate to a greater or less extent over the other; in some cases only a small portion of the second individual in the reversed position may exist. Very great irregularities are observed in nature in this respect. Moreover, the re-entering angles are often obliterated by the abnormal developments of one or other of the parts, and often only an indistinct line on some of the faces marks the division between the two individuals.

Penetration-twins are those in which two or more complete crystals interpenetrate, as it were crossing through each other. Normally, the crystals have a common center, which is the center of the axial system for both; practically, however, as in contact-twins, great irregularities occur.

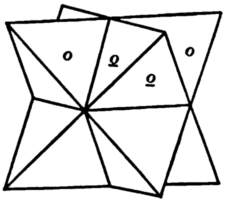
Examples of twins of this second kind are given in the annexed figures, Fig. 353 of fluorite, Fig. 354 of tetrahedrite, and Fig. 355 of chabazite. Other examples occur in the pages following, as, for instance, of the species staurolite (Figs. 408–411), the crystals of which sometimes occur in nature with almost the perfect symmetry demanded by theory. It is obvious that the distinction between contact- and penetration-twins is not of great importance, and the line cannot always be clearly drawn between them.

353.



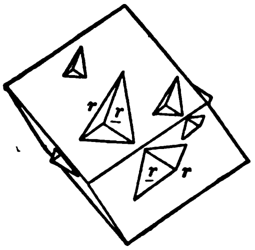
Fluorite.

354.



Tetrahedrite.

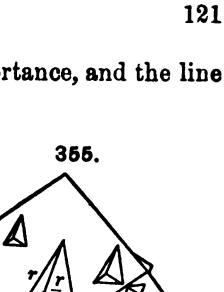
355.



Chabazite.

219. Paragenic and Metagenic Twins.—The distinction of paragenic and metagenic twins belongs rather to crystallogeny than crystallography. Yet the forms are often so obviously distinct that a brief notice of the distinction is important.

356.



Rutile.

In ordinary twins, the compound structure had its beginning in a nucleal compound molecule, or was compound in its very origin; and whatever inequalities in the result, these are only irregularities in the development from such a nucleus. But in others, the crystal was at first simple; and afterwards, through some change in itself or in the condition of the material supplied for its increase, received new layers, or a continuation, in a reversed position. This mode of twinning is *metagenic*, or a result subsequent to the origin of the crystal; while the ordinary mode is *paragenic*. One form of it is illustrated in Fig. 356. The middle portion had attained a length of half an inch or more, and then became geniculated simultaneously at either extremity. These geniculations are often repeated in rutile, and the ends of the crystal are thus bent into one another, and occasionally produce nearly regular prismatic forms.

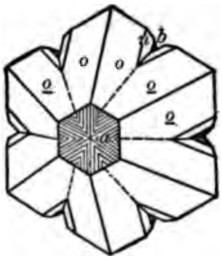
This metagenic twinning is sometimes presented by the successive layers of deposition in a crystal, as in some quartz crystals, especially amethyst, the inseparable layers, exceedingly thin, being of opposite kinds. In a similar manner, crystals of the triclinic feldspars, albite, etc., are often made up of thin plates parallel to *b* (010), by oscillatory composition, and the face *c* (001), accordingly, is finely striated parallel to the edge *c*, *b*.

220. Repeated Twinning, Polysynthetic and Symmetrical.—In the preceding paragraph one case of repeated twinning has been mentioned, that of the feldspars; it is a case of *parallel* repetition or parallel grouping in reversed position of successive crystalline lamellæ. This kind of twinning is often called *polysynthetic twinning*, the lamellæ in many cases being extremely thin, and giving rise to a series of parallel lines (striations) on a crystal face or a surface of cleavage. The triclinic feldspars show in many cases polysynthetic twinning and not infrequently on both *c* (001) and *b* (010), cf. p. 130. It is also observed with magnetite (Fig. 456), pyroxene, barite, etc.

Another kind of repeated twinning is illustrated by Figs. 357–362, where the successively reversed individuals are not parallel. In these cases the axes may, however, lie in a zone, as the prismatic twins of aragonite, or they may be inclined to each other, as in Fig. 359 of staurolite. In all such cases the repetition of the twinning tends to produce circular forms, when the angle between the two axial systems is an aliquot part of 360° (approximately). Thus six-rayed twinned crystals, consisting of three individuals (hence called *trillings*), occur with chrysoberyl (Fig. 357), or cerussite (Fig. 358), or staurolite

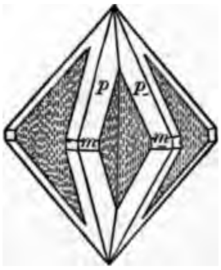
(Fig. 359), since three times the angle of twinning in each case is not far from 360°. Again, five-fold twins, or *fivelings*, occur in the octahedrons of gold and

357.



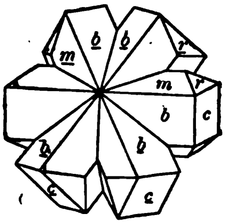
Chrysoberyl.

358.



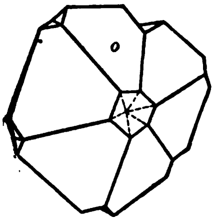
Cerussite.

359.



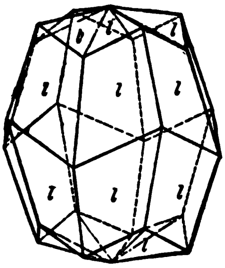
Staurolite.

360.



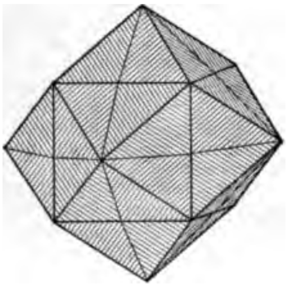
Spinel.

361.



Rutile.

362.



Phillipsite.

spinel (Fig. 360), since 5 × 70° 32′ = 360° (approx.). Eight-fold twins, or *eightlings*, of rutile (Figs. 361, 357) occur, since the angle of the axes in twinned position goes approximately eight times in 360°.

Repeated twinning of the symmetrical type often serves to give the compound crystal an apparent symmetry of higher grade than that of the simple individual, and the result is often spoken of as a kind of pseudo-symmetry (Art. **20**), cf. Fig. 397 of aragonite, which represents a *pseudo-hexagonal* crystal. Fig. 362 of phillipsite (cf. Figs. 422–424) is an interesting case, since it shows how a multiple twin of a monoclinic crystal may simulate an isometric crystal (dodecahedron).

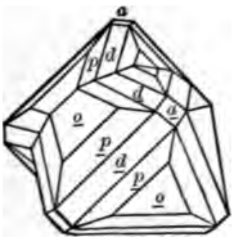
Compound crystals in which twinning exists in accordance with two laws at once are not of common occurence; an excellent example is afforded by staurolite, Fig. 411. They have also been observed on albite, orthoclase, and in other cases.

221. Secondary Twinning.—When there is reason to believe that the twinning has been produced subsequently to the original formation of the crystal, or crystalline mass, as, for example, by pressure, it is said to be *secondary*. Thus the calcite grains of a crystalline limestone often show such secondary twinning lamellæ. The same are occasionally observed (‖c, 001) in pyroxene crystals. Further, the polysynthetic twinning of the triclinic feldspars is often secondary in origin. This subject is further discussed on a later page, where it is also explained that in certain cases twinning may be produced artificially in a crystal individual—*e.g.*, in calcite (see Art. 261).

EXAMPLES OF IMPORTANT METHODS OF TWINNING.

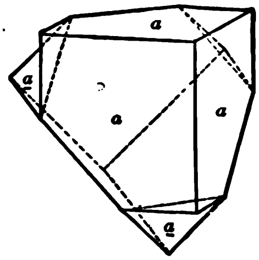
222. Isometric System.—With few exceptions the twins of the normal group of this system are of one kind, the twinning-axis an octahedral axis, and the twinning-plane consequently parallel to an *octahedral face;* in most cases, also, the latter coincides with the composition-plane. Fig. 350, p. 118,* shows this kind as applied to the simple octahedron; it is especially common with the spinel group of minerals, and is hence called in general a *spinel-twin*. Fig. 363 is a similar more complex form; Fig. 364 shows a cube twinned by this method, and Fig. 365 represents the same form but shortened in the direction of the octahedral axis, and hence having the anomalous aspect of a triangular pyramid. All these cases are contact-twins.

363.



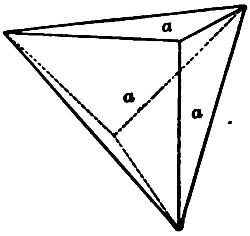
Galena.

364.



Copper.

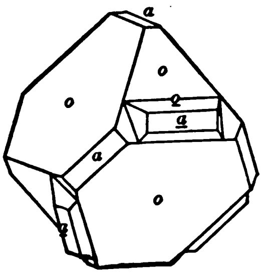
365.



Copper.

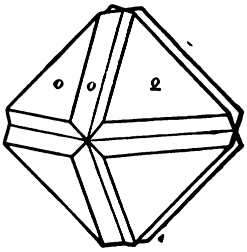
Penetration-twins, following the same law, are also common. A simple case of fluorite is shown in Fig. 353, p. 121; Fig. 366 shows one of galena; Fig. 367 is a repeated octahedral twin of haüynite, and Fig. 368 a dodecahedral twin of sodalite.

366.



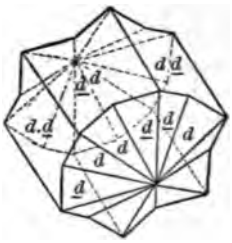
Galena.

367.



Haüynite.

368.



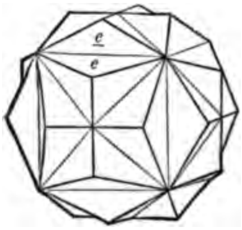
Sodalite.

---

* It will be noted that here and elsewhere the letters used to designate the faces on the twinned parts of crystals are distinguished by a subscript line.

223. In the *pyritohedral group* of the isometric system penetration-twins of the type shown in Fig. 369 are common (this form of pyrite is often called the *iron cross*). Here the cubic axis is the twinning-axis, and obviously such a twin is impossible in the normal group.

369.

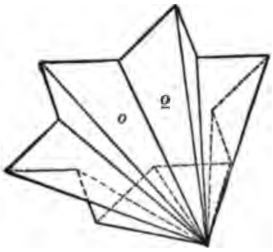


Pyrite.

Figs. 370 and 371 show analogous forms with parallel axes for crystals belonging to the tetrahedral group. The peculiar development of Fig. 370 of tetrahedrite is to be noted. Fig. 372 is a twin of the ordinary spinel type of another tetrahedral species, sphalerite; with it, complex forms with repeated twinning are not uncommon and sometimes polysynthetic twin lamellæ are noted.

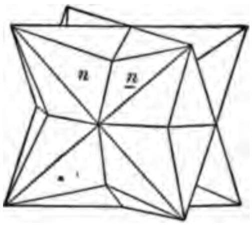
224. Tetragonal System.—The most common method is that where the twinning-plane is parallel to a face of the pyramid, *e* (101). It is especially characteristic of the species of the rutile group—viz., rutile and cassiterite; also similarly the allied species zircon. This is illustrated in Fig. 373, and again in Fig. 374. Fig. 375 shows a repeated twin of rutile, the twinning according to this law; the vertical axes of the successive six individuals lie in a plane, and an inclosed circle is the result. Another repeated twin of rutile according to the same law is shown in Fig. 361; here the successive vertical axes form a zigzag line; Fig. 376 shows an analogous twin of hausmannite.

370.



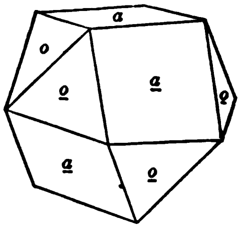
Tetrahedrite.

371.



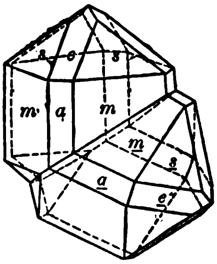
Eulytite.

372.



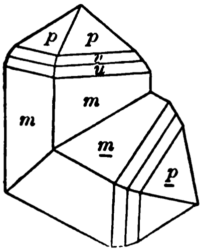
Sphalerite.

373.



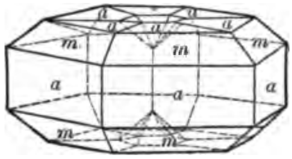
Cassiterite.

374.



Zircon.

375.

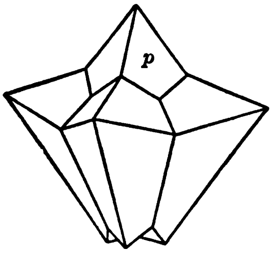


Rutile.

Another kind of twinning, twinning-plane parallel to a face of the pyramid (301), is shown in Fig. 377.

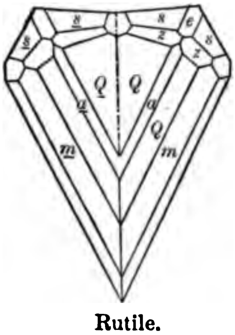
225. In the *pyramidal* group of the same system twins of the type of Fig. 378 are not rare. Here the vertical axis, *ċ*, is the twinning-axis; such a crystal may simulate one of the normal group.

376.



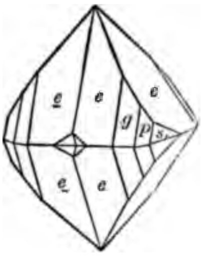
Hausmannite.

377.



Rutile.

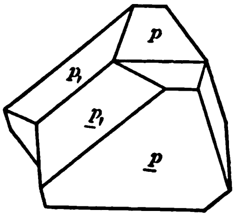
378.



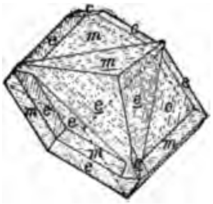
Scheelite.

In chalcopyrite, of the *sphenoidal* group, twinning with a face of the unit pyramid, *f* (111), as the twinning-plane is common (Fig. 379). As the angles differ but a small fraction of a degree from those of a regular octahedron, such twins often resemble closely spinel-twins. In Fig. 380 a repeated twin of this type has a pseudo-rhombohedral aspect. In Fig. 381 the twinning-plane is *e* (101). Other rarer kinds of twinning have also been noted.

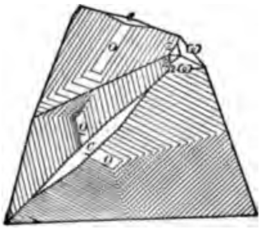
379.



380.



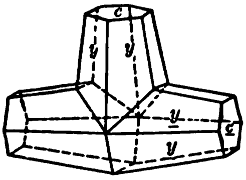
381.



Chalcopyrite.

226. Hexagonal System.—In the *hexagonal* division of this system twins are rare. An example is furnished by pyrrhotite, Fig. 382, where the twinning-plane is the pyramid $(10\bar{1}1)$, the vertical axes of the individual crystals being nearly at right angles to each other (since $0001 \wedge 10\bar{1}1 = 45° 8'$). Apparent cruciform twins of apatite, of the pyramidal group, have been noted in some rare cases. Here the diagonal pyramid *s* $(11\bar{2}1)$ was the plane which seemed to be the twinning-plane. These cases need confirmation.

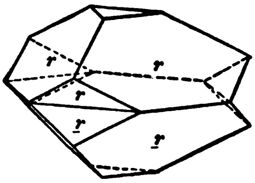
382.



Pyrrhotite.

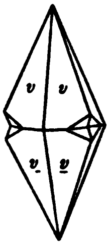
227. In the species belonging to the trigonal or *rhombohedral* division, twins are common. Thus the twinning-axis may be the vertical axis, as in the contact-twins of Figs. 383 and 384, or the penetration-twins of Figs. 348, 385. Or the twinning-plane may be the obtuse rhombohedron *e* $(01\bar{1}2)$, as in Fig. 386, the vertical axes crossing at angles of 127½° and 52½°; these forms are often curiously distorted, as in Figs. 387, 388. Again, the twinning-plane may be *r* $(10\bar{1}1)$, as in Fig. 389, the vertical axes nearly at right angles (90¾°); or $(0\bar{2}21)$, as in Fig. 390, the axes inclined 53¾° and 126¼°. In Fig. 391 of gmelinite the twinning-plane is the rhombohedron $(30\bar{3}2)$, which corresponds in angle with the common fundamental form of the allied species chabazite.

383.



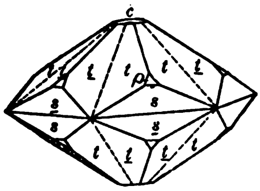
Calcite.

384.



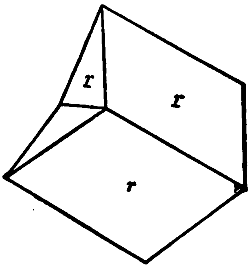
Calcite.

385.

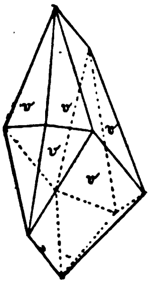


Phacolite.

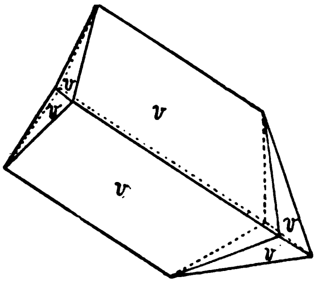
386.



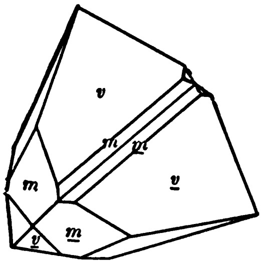
387.



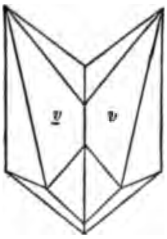
388.



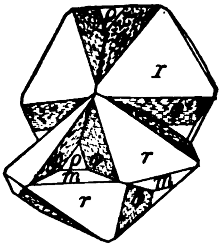
389.



390.



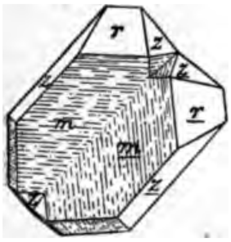
391.



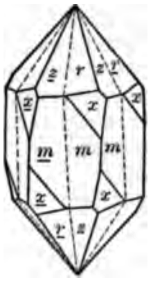
Figs. 386–390, Calcite. Fig. 391, Gmelinite.

In the *trapezohedral* group, the species quartz shows several methods of twinning. In Fig. 392 the twinning-plane is the diagonal pyramid ξ (11$\bar{2}$2), the axes crossing at angles of 84½° and 95½°. In Fig. 393 the twinning-axis is $\dot{c}$, the axes hence parallel, the individuals both right- or both left-handed but unsymmetrical, *r* (10$\bar{1}$1) then parallel to and coinciding with *z* (01$\bar{1}$1). The resulting forms, as in Fig. 393, are mostly penetration-twins, and the parts are often very irregularly united, as shown by dull areas (*z*) on the plus rhombohedral face (*r*); otherwise these twins are recognized by pyro-electrical phenomena. In Fig. 394 the twinning-plane is *a* (11$\bar{2}$0)—the *Brazil law*—the individuals respectively right- and left-handed and the twin symmetrical with reference to an *a*-face; these are usually irregular penetration-twins; in these twins *r* and $\underline{r}$, also *z* and $\underline{z}$, coincide. These twins often show, in converging polarized light, the phenomenon of Airy's spirals. It may be added that pseudo-twins of quartz are common—that is, groups of crystals which *nearly* conform to some more or less complex twinning law, but where the grouping is nevertheless only accidental. See also the remarks in Art. **232** about Fig. 433.

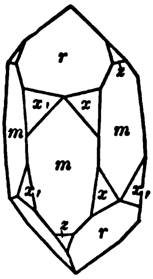
392.



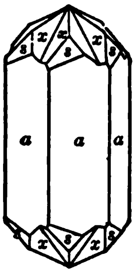
393.



394.



395.

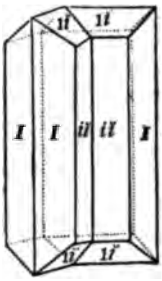


Figs. 392–394, Quartz. Fig. 395, Phenacite.

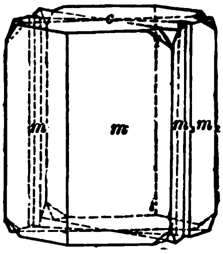
In Fig. 395 of phenacite (cf. p. 80 *et seq.*) the vertical axis is obviously the twinning-axis.

228. Orthorhombic System.—In the orthorhombic system the commonest method of twinning is that where the twinning-plane is a face of a prism of

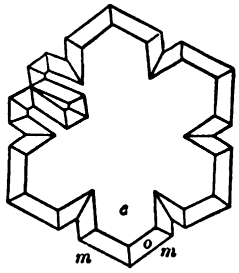
396.



397.

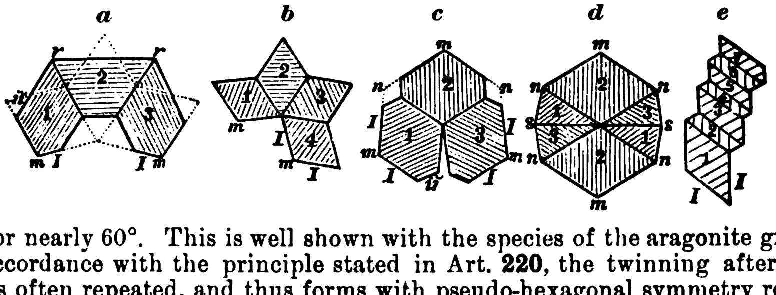


398.



Figs. 396–398, Aragonite.

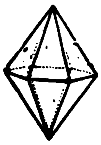
399.



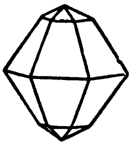
60°, or nearly 60°. This is well shown with the species of the aragonite group. In accordance with the principle stated in Art. **220**, the twinning after this law is often repeated, and thus forms with pseudo-hexagonal symmetry result. Fig. 396 shows a simple twin of aragonite; Figs. 397, 398 repeated forms exhibiting the irregularities on the faces due to the fact that the prismatic angle is not exactly 60°. Fig. 399, *a–e*, show further some of the methods of composition which have been noted; in *e* the twinning is polysynthetic.

With witherite (and bromlite), apparent hexagonal pyramids (Figs. 400, 401) are common, but the true complex twinning is revealed in polarized light, as noted later.

400.



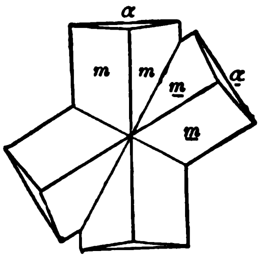
401.



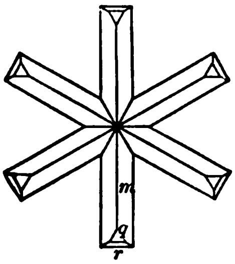
Witherite.

Twinning of the same type, but where a dome of 60° is twinning-plane, is common with arsenopyrite (tw. pl. *e* (101), as shown in Figs. 402, 403; also Fig. 404 of columbite, but compare Fig. 347 and remarks in Art. **217**. Another example is given in Fig. 357 of alexandrite (chrysoberyl). Chrysolite, manganite, humite, are other species with which this kind of twinning is common.

402.

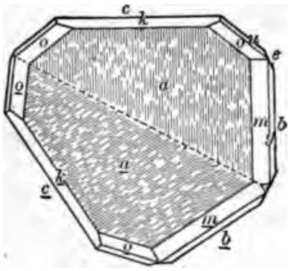


403.



Arsenopyrite.

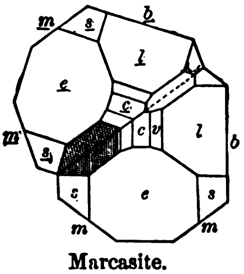
404.



Columbite.

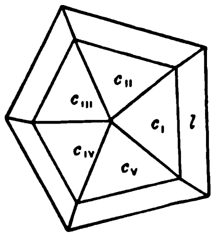
Another common method of twinning is that where the twinning is parallel to a face of a prism of about 70½°, as shown in Fig. 405. With this method symmetrical fivelings not infrequently occur (Figs. 406, 407).

405.



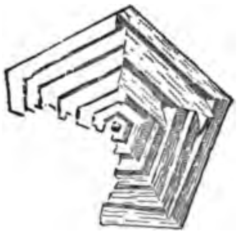
Marcasite.

406.



Marcasite.

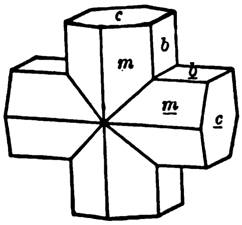
407.



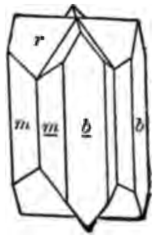
Arsenopyrite.

The species staurolite illustrates three kinds of twinning. In Fig. 408 the

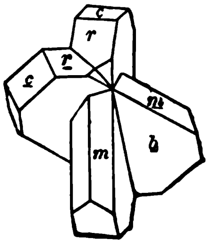
408.



409.

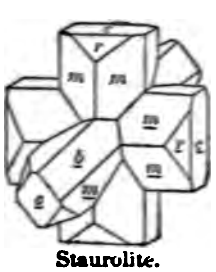


410.



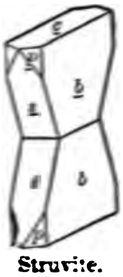
twinning-plane is (032), and since (001 ∧ 032) = 45° 41′, the crystals cross nearly at right angles. In Fig. 409 the twinning-plane is the prism (230). In Fig. 410 it is the pyramid (232): the crystals then crossing at angles of about 60°, stellate trillings occur (see Fig. 359), and indeed more complex forms. In Fig. 411 there is twinning according to both (032) and (232).

411.



Staurolite.

412.

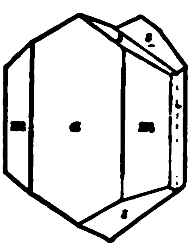


Struvite.

In the hemimorphic group, twins of the type shown in Fig. 412, with *c* as the twinning-plane, are to be noted.

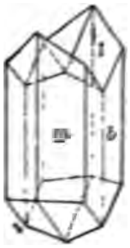
229. Monoclinic System.—In the monoclinic system, twins with the vertical axis as twinning-axis are common; this is illustrated by Fig. 413 of augite (pyroxene), Fig. 414 of gypsum, and Fig. 415 of orthoclase (see also Fig. 352, p. 120). With the latter species these twins are called *Carlsbad twins* (because common in the trachyte of Carlsbad, Bohemia): they may be contact-twins (Fig. 352), or irregular penetration-twins (Fig. 415). In Fig. 352 it is to be noted that *c* and *x* fall nearly in the same plane.

413.



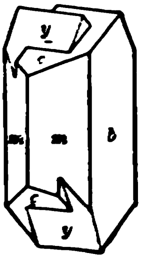
Augite.

414.



Gypsum.

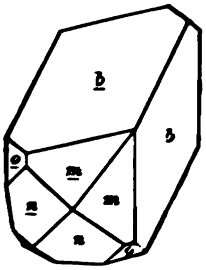
415.



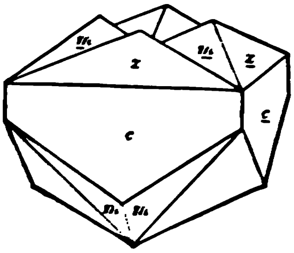
Orthoclase.

In Fig. 416, also of orthoclase, the twinning-plane is the clinodome (021), and since (001 ∧ 021) = 44° 56½′, this method of twinning yields nearly square prisms. These twins are called *Baveno twins* (from a prominent locality at Baveno, Italy): they are often repeated (Fig. 417). In Fig. 418 a *Manebach twin* is shown: here the twinning-plane is *c* (001). Other rarer types of twinning have been noted with orthoclase. Polysynthetic twinning with *c* (001) as twinning-plane is common with pyroxene (cf. Fig. 430, p. 131).

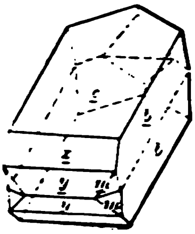
416.



417.



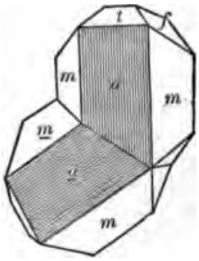
418.



Orthoclase.

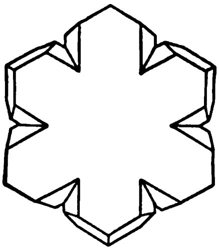
Twins of the aragonite-chrysoberyl type, are not uncommon with monoclinic species, having a prominent 60° prism (or dome), as in Fig. 419. Stellate twins after this law are common with chondrodite and clinohumite. An analogous twin of pyroxene is shown in Fig. 420; here the pyramid $(\bar{1}22)$ is the twinning-plane, and since $(010 \wedge \bar{1}22) = 59° 21'$, the crystals cross at angles of nearly 60°; further, the orthopinacoids fall nearly in a common zone, since $(100 \wedge \bar{1}22) = 90° 9'$. In Fig. 421 the twinning-plane is the orthodome (101). Phillipsite and harmotome exhibit multiple twinning, and the crystals often show pseudo-symmetry. Fig. 422 shows a cruciform fourling with *c* (001) as twinning-plane, the twinning shown by the striations on the side face. This is compounded in Fig. 423 with twinning-plane (011), making nearly square prisms, and this further repeated with *m* (110) as twinning-plane yields the form in Fig. 424, or even Fig. 362, p. 122, resembling an isometric dodecahedron, each face showing a fourfold striation.

419.



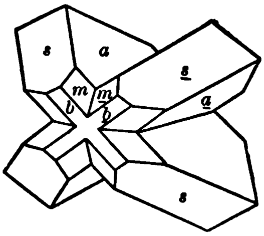
Wolframite.

420.



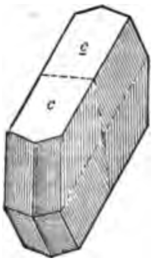
Pyroxene.

421.

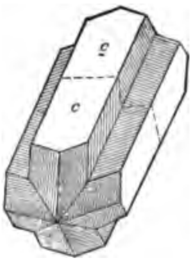


Pyroxene.

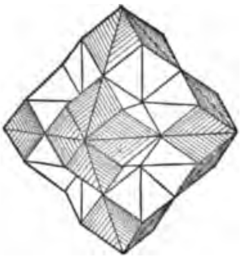
422.



423.



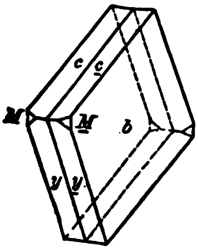
424.



Phillipsite.

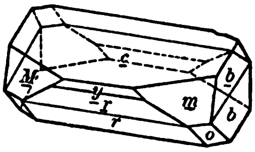
230. Triclinic System.—The most interesting twins of the triclinic system are those shown by the feldspars. Twinning with *b* (010) as the twinning-plane is very common, especially polysynthetic twinning yielding thin parallel lamellæ, shown by the striations on the face *c* (or the corresponding cleavage-surface), and also clearly revealed in polarized light. This is known as the *albite law* (Fig. 425). Another important method (Fig. 426) is that of the *pericline law;* the twinning-axis is the crystallographic axis *b*. Here the twins are united by a section (rhombic section) shown in the figure and further explained under the feldspars. Polysynthetic twinning after this law is common, and hence a cleavage-mass may show two sets of striations, one on the surface parallel to *c* (001) and the other on that parallel to *b* (010). The angle made by these last striations with the edge 001/010 is characteristic o the particular triclinic species, as noted later.

425.



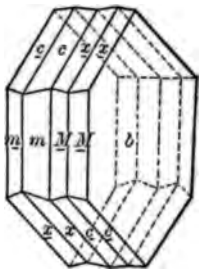
Labradorite.

426.



Albite.

427.



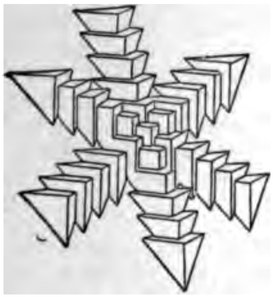
Albite.

Twins of albite of other rarer types also occur, and further twins simila to the Carlsbad, Baveno, and Manebach twins of orthoclase. Fig. 427 show twinning according to both the albite and Carlsbad types.

REGULAR GROUPING OF CRYSTALS.

231. Parallel Grouping.—Connected with the subject of twin crystals i that of the parallel position of associated crystals of the same species, or o different species.

428.



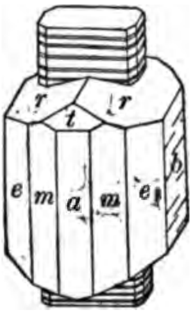
Crystals of the same species occurring together are very commonly i parallel position. In this way large crystals, as o calcite, quartz, fluorite, are sometimes built up o smaller individuals grouped together with corresponding faces parallel. This parallel grouping is ofte seen in crystals as they lie on the supporting rock On glancing the eye over a surface covered wit crystals a reflection from one face will often b accompanied by reflections from the correspondin face in each of the other crystals, showing that th crystals are throughout similar in their positions.

With many species, complex crystalline forms resul from the growth of parallel partial crystals in the direction of the crystallographic axes, or axes of symmetry

429.

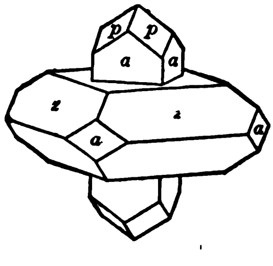
Copper.

430.



Amphibole enclosing pyroxene in parallel position.

431.



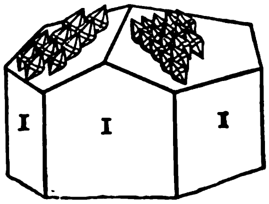
Xenotime enclosing zircon in parallel position.

Thus *dendritic* forms, resembling branching vegetation, often of great delicacy, are seen with gold, copper, argentite, and other species, especially those of the isometric system. This is shown in Fig. 428 (ideal), and again in Fig. 429, where the twinned and flattened cubes (cf. Fig. 365, p. 123) are grouped in directions corresponding to the diagonals of an octahedral face which is the twinning-plane.

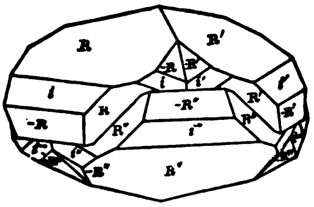
232. Parallel Grouping of Unlike Species.—Crystals of different species often show the same tendency to parallelism in mutual position. This is true most frequently of species which are more or less closely similar in form and composition. Crystals of albite, implanted on a surface of orthoclase, are sometimes an example of this; crystals of amphibole and pyroxene (Fig. 430), of zircon and xenotime (Fig. 431), of various kinds of mica, are also at times observed associated in parallel position.

The same relation of position also occasionally occurs where there is no connection in composition, as the crystals of rutile on tabular crystals of hematite, the vertical axes of the former coinciding with the lateral axes of the latter. Crystals of calcite have been observed whose rhombohedral faces had a series of quartz crystals upon them, all in parallel position (Fig. 432); sometimes three such quartz crystals, one on each rhombohedral face, entirely envelop the calcite, and unite with re-entering angles to form pseudo-twins (rather trillings) of quartz after calcite. A similar occurrence from Specimen Mountain, in the Yellowstone Park, is shown in Fig. 433.

432.



433.



IRREGULARITIES OF CRYSTALS.

233. The laws of crystallization, when unmodified by extrinsic causes, should produce forms of exact geometrical symmetry, the angles being not only equal, but also the homologous faces of crystals and the dimensions in the directions of like axes. This symmetry is, however, so uncommon that it can hardly be considered other than an ideal perfection. The various possible kinds of symmetry, and the relation of this ideal geometrical symmetry to the actual crystallographic symmetry, have been discussed in Arts. **14** and **18** *et seq.* Crystals are very generally distorted, and often the fundamental forms are so completely disguised that an intimate familiarity with the possible irregularities is required in order to unravel their complexities. Even the angles may occasionally vary rather widely.

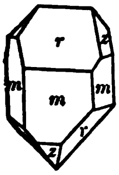
The irregularities of crystals may be treated of under several heads: 1, *Variations of form and dimensions;* 2, *Imperfections of surface;* 3, *Variations of angles;* 4, *Internal imperfections and impurities.*

1. VARIATIONS IN THE FORMS AND DIMENSIONS OF CRYSTALS.

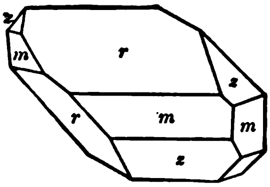
234. Distortion in General.—The variations in the forms of crystals, or, in other words, their *distortion*, may be *irregular* in character, certain faces being larger and others smaller than in the ideal geometrical solid. On the other hand, it may be *symmetrical*, giving to the distorted form the symmetry of a group or system different from that to which it actually belongs. The former case is the common rule, but the latter is the more interesting.

235. Irregular Distortion.—As stated above and on p. 11, all crystals show to a greater or less extent an irregular or accidental variation from the ideal geometrical form. This distortion, if not accompanied by change in the interfacial angles, has no particular significance, and does not involve any deviation from the laws of crystallographic symmetry. Figs. 434, 435 show distorted crystals of quartz; they may be compared with the ideal form, Fig. 266, p. 83. Fig. 436 is an ideal and Fig. 437 an actual crystal of lazulite. So, too, Fig. 438 is a distorted crystal of apatite, to be compared with Fig. 216, p. 72.

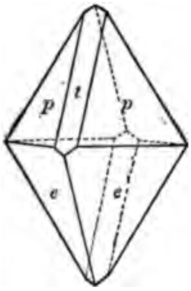
434.



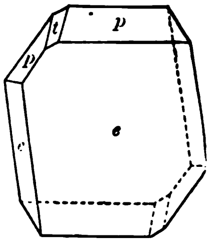
435.



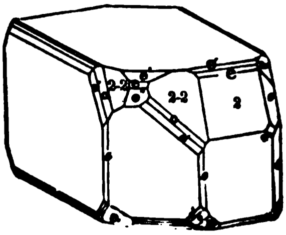
436.



437.



438.



Apatite.

The correct identification of the forms on a crystal is rendered much more difficult because of this prevailing distortion, especially when it results in the entire *obliteration* of certain faces by the enlargement of others. In deciphering the distorted crystalline forms it must be remembered that while the appearance of the crystals may be entirely altered, the interfacial angles remain the same; moreover, like faces are physically alike—that is, alike in degree of luster, in striations, and so on. Thus the prismatic faces of quartz show almost always characteristic horizontal striations.

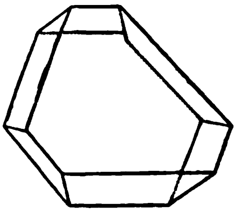
In addition to the variations in form which have just been described, still greater irregularities are due to the fact that, in many cases, crystals in nature are attached either to other crystals or to some rock surface, and in consequence of this are only partially developed. Thus quartz crystals are generally attached by one extremity of the prism, and hence have only one set of pyramidal faces; perfectly formed crystals, having the double pyramid complete, are rare.

236. Symmetrical Distortion.—The most interesting examples of the symmetrical distortion of crystalline forms are found among crystals of the isometric system. An elongation in the direction of one cubic axis may give the appearance of tetragonal symmetry, or that in the direction of two cubic axes of orthorhombic symmetry; while in the direction of an octahedral axis a lengthening or shortening gives rise to forms of apparent rhombohedral symmetry. Such cases are common with native gold, silver, and copper.

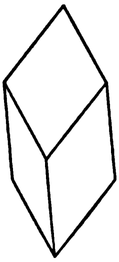
A *cube* lengthened or shortened along one axis becomes a right square prism, and if varied in the direction of two axes is changed to a rectangular prism. Cubes of pyrite, galena, fluorite, etc., are often thus distorted. It is very unusual to find a cubic crystal that is a true symmetrical cube. In some species the cube or octahedron (or other isometric form) is lengthened into a capillary crystal or needle, as happens in cuprite and pyrite.

An octahedron *flattened* parallel to a face—that is, in the direction of a trigonal interaxis—is reduced to a tabular crystal resembling a rhombohedral crystal with basal plane (Fig. 439). If *lengthened* in the same direction, to the obliteration of the terminal octahedral faces, it becomes an acute rhombohedron (cf. Fig. 440).

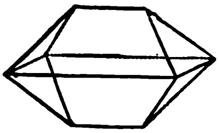
439.



440.



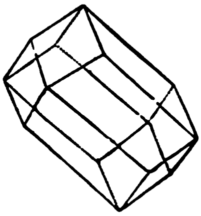
441.



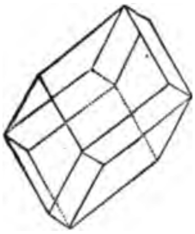
When an octahedron is extended in the direction of a line between two opposite edges, or that of a rhombic interaxis, it has the general form of a rectangular octahedron; and still farther extended, as in Fig. 441, it is changed to a rhombic prism with dihedral summits (spinel, fluorite, magnetite). The figure represents this prism lying on its acute edge.

The *dodecahedron* lengthened in the direction of a diagonal between the obtuse solid angles—that is, that of a trigonal interaxis—becomes a six-sided prism with three-sided summits, as in Fig. 442. If shortened in the same direction, it becomes a *short* prism of the same kind (Fig. 443). Both resemble rhombohedral forms and are common in garnet (compare Fig. 234, p. 76, of calcite). When lengthened in the direction of one of the cubic axes, the dodecahedron becomes a square prism with pyramidal summits (Fig. 444), and shortened along the same axis it is reduced to a square octahedron, with truncated basal angles (Fig. 445).

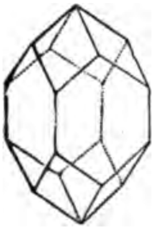
442.



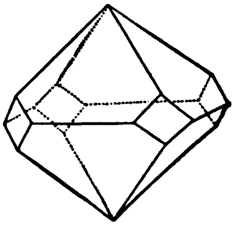
443.



444.



445.

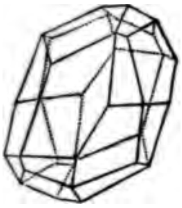


The trapezohedron elongated in the direction of an octahedral (trigonal) axis assumes rhombohedral (trigonal) symmetry. The resulting forms referred to the usual hexagonal axes for both (211) and (311) are as follows:

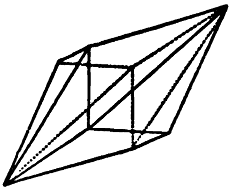
(211)	$(10\bar{1}4)$	(311)	$(20\bar{2}5)$
$(21\bar{1})$	$(12\bar{3}2)$	$(31\bar{1})$	(2243)
$(11\bar{2})$	$(10\bar{1}0)$	$(3\bar{1}\bar{1})$	$(40\bar{4}1)$

For (211) the resulting form is first that of Fig. 446, and if still farther lengthened, to the obliteration of some of the faces, it becomes a scalenohedron (Fig. 447). This has been observed in fluorite. Only twelve faces are here present out of the twenty-four. If the elongation of this trapezohedron (211) takes place along a cubic axis, it becomes a double eight-sided pyramid with four-sided summits (Fig. 448); or if these summit planes are obliterated by a farther extension, it becomes a complete eight-sided double pyramid (Fig. 449).

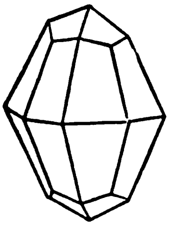
446.



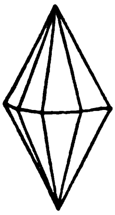
447.



448.

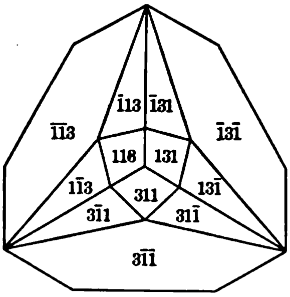


449.

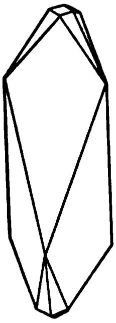


The accompanying figures illustrate the rhombohedral distortion of the trapezohedron (311), cf. Fig. 93, p. 88. Fig. 450 shows the faces as projected on a plane normal to an octahedral axis, and Fig. 451 gives the resulting distorted form, resembling an acute rhombohedron ($40\bar{4}1$), a diagonal pyramid ($22\bar{4}3$), and an obtuse terminal rhombohedron ($20\bar{2}5$). The native gold from the White Bull mine, Oregon, sometimes consists of a slender string of such rhombohedral crystals, and not infrequently there are minor branches in the direction of two or more of the other octahedral axes (Figs. 452, 453).

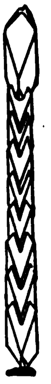
450.



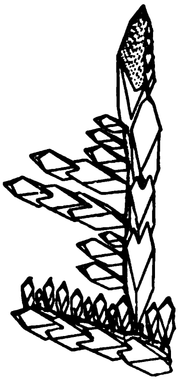
451.



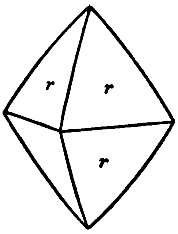
452.



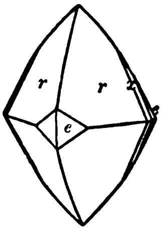
453.



454.



455.



The trisoctahedron is rare as a prominent form, but a curious example of its distortion is given in Figs. 454, 455 of pyrite from French Creek, Penn. The form, apparently tetragonal (or orthorhombic), shows only eight faces of the trisoctahedron *r* (332), and these are strongly rounded; faces of the pyritohedron *e* (210) also appear as a subordinate form.

Similarly the tetrahexahedron and hexoctahedron may show distortion of the same kind. Further examples are to be found in the other systems.

2. IMPERFECTIONS OF THE SURFACES OF CRYSTALS.

237. Striations Due to Oscillatory Combinations.—The parallel lines or furrows on the surfaces of crystals are called *striæ* or *striations,* and such surfaces are said to be *striated.*

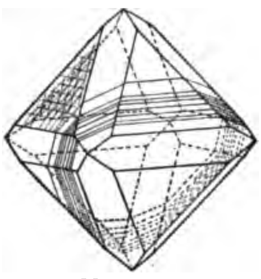
Each little ridge on a striated surface is enclosed by two narrow planes more or less regular. These planes often correspond in position to different faces of the crystal, and these ridges have been formed by a continued oscillation in the operation of the causes that give rise, when acting uninterruptedly, to enlarged faces. By this means, the surfaces of a crystal are marked in parallel lines, with a succession of narrow planes meeting at an angle and constituting the ridges referred to.

This combination of different planes in the formation of a surface has been termed *oscillatory combination.* The horizontal striations on prismatic crystals of quartz are examples of this combination, in which the oscillation has taken place between the prismatic and rhombohedral faces. Thus crystals of quartz are often tapered to a point, without the usual pyramidal terminations.

Other examples are the striations on the cubic faces of pyrite parallel to the intersections of the cube with the faces of the pyritohedron; also the striations on magnetite due to the oscillation between the octahedron and dodecahedron. Prisms of tourmaline are very commonly bounded vertically by three convex surfaces, owing to an oscillatory combination of the faces in the prismatic zone.

238. Striations Due to Repeated Twinning.—The striations of the basal plane of albite and other triclinic feldspars, also of the rhombohedral surfaces of some calcite, have been explained in Art. 220 as due to polysynthetic twinning. This is illustrated by Fig. 456 of magnetite from Port Henry, N. Y. (Kemp.)

456.



Magnetite.

239. Markings from Erosion and Other Causes.—The faces of crystals are not uncommonly uneven, or have the crystalline structure developed as a consequence of etching by some chemical agent. Cubes of galena are often thus uneven, and crystals of lead sulphate (anglesite) or lead carbonate (cerussite) are sometimes present as evidence with regard to the cause. Crystals of numerous other species, even of corundum, spinel, quartz, etc., sometimes show the same result of partial change over the surface—often the incipient stage in a process tending to a final removal of the whole crystal. Interesting investigations have been made by various authors on the action of solvents on different minerals, the actual structure of the crystals being developed in this way. This method of etching is fully discussed, with illustrations, in another place (Art. 265).

The markings on the surfaces of crystals are not, however, always to be ascribed to etching. In most cases such depressions, as well as the minute elevations upon the faces having the form of low pyramids (so-called *vicinal* prominences), are a part of the original molecular growth of the crystal, and often serve to show the successive stages in its history. They may be imperfections arising from an interrupted or disturbed development of the form, the perfectly smooth and even crystalline faces being the result of completed action free from disturbing causes. Examples of the markings referred to occur on the crystals of most minerals, and conspicuously so on the rhombohedral faces of quartz.

Faces of crystals are often marked with angular elevations more or less distinct, which are due to oscillatory combination. Octahedrons of fluorite are common which have for each face a surface of minute cubes, proceeding from an oscillation between the cube and octahedron. Sometimes an examination of such a crystal shows that though the form is apparently octahedral, there are no octahedral faces present at all. Other similar cases could be mentioned.

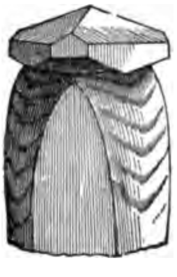
Whatever their cause, these minute markings are often of great importance as revealing the true molecular symmetry of the crystal. For it follows from the symmetry of crystallization that like faces must be physically alike—that is, in regard to their surface character; it thus often happens that on all the crystals of a species from a given locality, or perhaps from all localities, the same planes are etched or roughened alike. There is much uniformity on the faces of quartz crystals in this respect.

240. Curved surfaces may result from (*a*) oscillatory combination; or (*b*) some independent molecular condition producing curvatures in the laminæ of the crystal; or (*c*) from a mechanical cause.

Curved surfaces of the *first* kind have been already mentioned (Art. **237**). A singular curvature of this nature is seen in Fig. 457, of calcite; in the lower part traces of a scalenohedral form are apparent which was in oscillatory combination with the prismatic form.

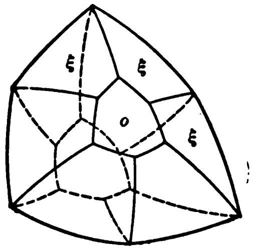
Curvatures of the *second* kind sometimes have all the faces convex. This is the case in crystals of diamond (Fig. 458), some of which are almost spheres. The mode of curvature, in which all the faces are equally convex, is less common than that in which a convex surface is opposite and parallel to a corresponding concave surface. Rhombohedrons of dolomite and siderite are usually thus curved. The feathery curves of frost on windows and the flagging-stones of pavements in winter are other examples. The alabaster rosettes from the Mammoth Cave, Kentucky, are similar. Stibnite crystals sometimes show very remarkable curved and twisted forms.

457.



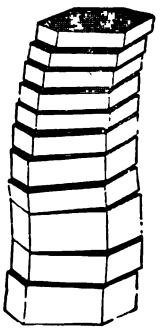
Calcite.

458.



Diamond.

459.



Beryl.

A *third* kind of curvature is of *mechanical origin*. Sometimes crystals appear as if they had been broken transversely into many pieces, a slight displacement of which has given a curved form to the prism. This is common in tourmaline and beryl. The beryls of Monroe, Conn., often present these interrupted curvatures, as represented in Fig. 459.

Crystals not infrequently occur with a deep pyramidal depression occupying the place of each plane, as is often observed in common salt, alum, and sulphur. This is due in part to their rapid growth.

3. VARIATIONS IN THE ANGLES OF CRYSTALS.

241. The greater part of the distortions described in Arts. **235**, **236** occasion no change in the interfacial angles of crystals. But those imperfections that produce convex, curved, or striated faces necessarily cause such variations. Furthermore, circumstances of heat or pressure under which the crystals were formed may sometimes have resulted not only in distortion of form, but also some variation in angle. The presence of impurities at the time of crystallization may also have a like effect.

Still more important is the change in the angles of completed crystals which is caused by subsequent pressure on the matrix in which they were formed, as, for example, the change which may take place during the more or less complete metamorphism of the enclosing rock.

The change of composition resulting in pseudomorphous crystals (see Art. **252**) is generally accompanied by an irregular change of angle, so that the pseudomorphs of a species vary much in angle.

In general it is safe to affirm that, with the exception of the irregularities arising from imperfections in the process of crystallization, or from the subsequent changes alluded to, variations in angles are rare, and the constancy of angle alluded to in Art. **11** is the universal law.

In cases where a greater or less variation in angle is observed in the crystals of the same species from different localities, the cause for this can usually be found in a difference of chemical composition. In the case of isomorphous compounds it is well known that an exchange of corresponding chemically equivalent elements may take place without a change of form, though usually accompanied with a slight variation in the fundamental angles.

The effect of heat upon the form of crystals is alluded to in Art. **415**.

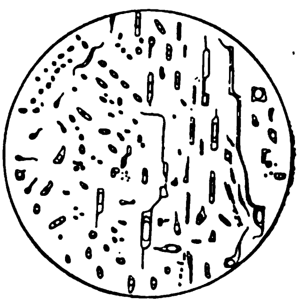
4. INTERNAL IMPERFECTIONS AND INCLUSIONS.

242. The transparency of crystals is often destroyed by disturbed crystallization; by impurities taken up from the solution during the process of crystallization; or, again, by the presence of foreign matter resulting from partial chemical alteration. The general name, *inclusion,* is given to any foreign body enclosed within the crystal, whatever its origin. These inclusions are extremely common; they may be gaseous, liquid, or solid; visible to the unaided eye or requiring the use of the microscope.

Rapid crystallization is a common explanation of inclusions. This is illustrated by quartz crystals containing large cavities full or nearly full of water (in the latter case, these showing a movable bubble); or, they may contain sand or iron oxide in large amount. In the case of calcite, crystallization from a liquid largely charged with a foreign material, as quartz sand, may result in the formation of crystals in which the impurity makes up as much as two-thirds of the whole mass; this is seen in the famous Fontainebleau limestone, and similarly in that from other localities.

243. Liquid and Gas Inclusions.—Attention was early called by Brewster to the presence of fluids in cavities in certain minerals, as quartz, topaz, beryl, chrysolite, etc. In later years this subject has been thoroughly studied by Sorby, Zirkel, Vogelsang, Fischer, Rosenbusch, and others. The nature of the liquid can often be determined, as by its refractive power, or by special physical test (*e.g.*, determination of the critical point in the case of CO_2), or by chemical examination. In the majority of cases the observed liquid is simply water; but it may be the salt solution in which the crystal was formed, and not infrequently, especially in the case of quartz, liquid carbon dioxide (CO_2), as first proved by Vogelsang. These liquid inclusions are marked as such, in many cases, by the presence in the cavity of a movable bubble of gas. Occasionally cavities contain two liquids, as water and liquid carbon dioxide, the latter then inclosing a bubble of the same substance as gas (cf. Fig. 460). Interesting experiments can be made with sections showing such inclusions (cf. literature, p. 141). The mixture of gases yielded by smoky quartz, meteoric iron, and other substances, on the application of heat, has been analyzed by Wright.

460.

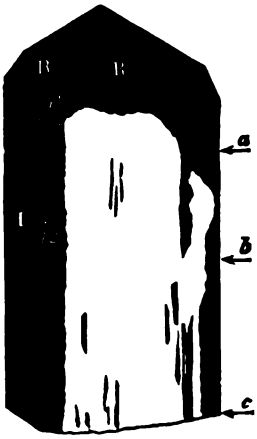


Beryllonite.

In some cases the cavities appear to be empty; if they then have a regular form determined by the crystallization of the species, they are often called *negative crystals.* Such cavities are commonly of secondary origin, as remarked on a later page.

244. Solid Inclusions.—The solid inclusions are almost infinite in their variety. Sometimes they are large and distinct, and can be referred to known mineral species, as the scales of göthite or hematite, to which the peculiar character of aventurine feldspar is due. Magnetite is a very common impurity in many minerals, appearing, for example, in the Pennsbury mica; quartz is also often mechanically mixed, as in staurolite and gmelinite. On the other hand, quartz crystals very commonly inclose foreign material, such as chlorite, tourmaline, rutile, hematite, asbestus, and many other minerals. (Cf. also Arts. **245**, **246**.)

461.



An interesting example of the inclosure of one mineral by another is afforded by the annexed figures of tourmaline enveloping orthoclase.* Fig. 461 shows the crystal of tourmaline; and cross sections of it at the points indicated (*a*, *b*, *c*) are given by Figs. 462, 463, 464. The latter show that the feldspar increases in amount in the lower part of the crystal, the tourmaline being merely a thin shell. Similar specimens from the same locality (Port Henry, Essex Co., N. Y.) show that there is no necessary connection between the position of the tourmaline and that of the feldspar.

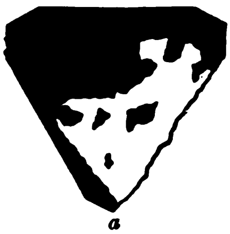
Similar occurrences are those of trapezohedrons of garnet, where the latter is a mere shell, inclosing calcite, or sometimes epidote or quartz (Fig. 472).

---

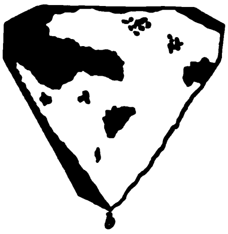
* E. H. Williams, Am. J. Sc., 11, 273, 1876.

Analogous cases have been explained by some authors as being due to partial pseudomorphism, the alteration progressing from the center outward.

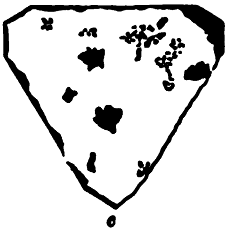
462.



463.



464.

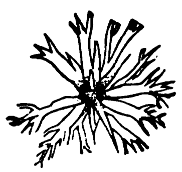


The inclusions may consist of a heterogeneous mass of material; as the granitic matter seen in orthoclase crystals in a porphyritic granite; or the feldspar, quartz, etc., sometimes inclosed in large coarse crystals of beryl or spodumene, occurring in granite veins.

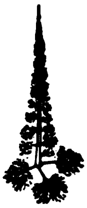
245. Microlites, Crystallites.—The microscopic crystals observed as inclusions may sometimes be referred to known species, but more generally their true nature is doubtful. The term *microlites*, proposed by Vogelsang, is often used to designate the minute inclosed crystals; they are generally of needle-like form, sometimes quite irregular, and often very remarkable in their arrangement and groupings; some of them are exhibited in Fig. 470 and Fig. 471, as explained below. Where the minute individuals belong to known species they are called, for example, feldspar microlites, etc.

Crystallites is an analogous term used by Vogelsang to cover those minute forms which have not the regular exterior form of crystals, but may be considered as intermediate between amorphous matter and true crystals. Some of the forms are shown in Figs. 465–469; they are often observed in glassy volcanic rocks, and also in furnace-slags. A series of names has been given to varieties of crystallites, such as globulites, margarites, etc. Trichite and belonite are names introduced by Zirkel; the former name is derived from *θρίξ, hair*; trichites, like that in Fig. 469, are common in obsidian.

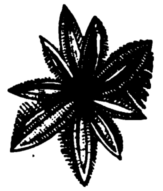
465.



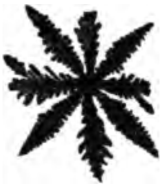
466.



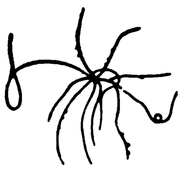
467.



468.



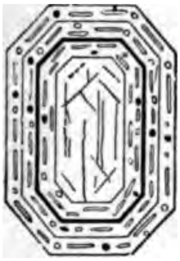
469.



The microscopic inclusions may also be of an irregular glassy nature; this kind is often observed in crystals which have formed from a molten mass, as lava or the slag of an iron furnace.

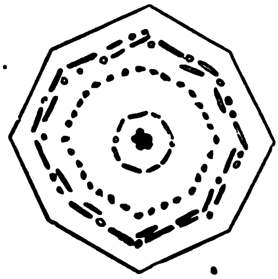
246. Symmetrically Arranged Inclusions.—In general, while the solid inclusions sometimes occur quite irregularly in the crystals, they are more generally arranged with some evident reference to the symmetry of the form, or external faces of the crystals. Examples of this are shown in the following figures. Fig. 470 exhibits a crystal of augite, inclosing magnetite, feldspar and nephelite microlites, etc. Fig. 471 shows a crystal of leucite, a species whose crystals very commonly inclose foreign matter. Fig. 472 shows a section of a crystal of garnet, containing quartz.

470.



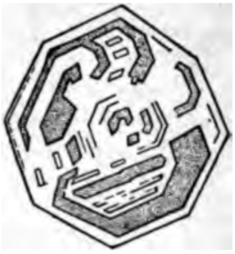
Augite (Zirkel).

471.



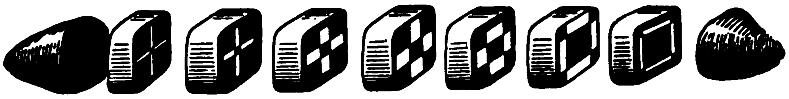
Leucite (Zirkel).

472.



Garnet inclosing quartz (Heddle).

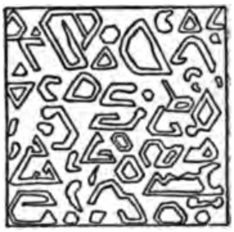
473.



Andalusite.

Another striking example is afforded by andalusite (Fig. 473), in which the inclosed carbonaceous impurities are of considerable extent and remarkably arranged, so as to yield symmetrical figures of various forms. Staurolite occasionally shows analogous carbonaceous impurities symmetrically distributed.

474.



The magnetite common as an inclusion in muscovite, alluded to above, is always symmetrically disposed, usually parallel to the directions of the percussion-figure (Fig. 477, p. 149). The asterism of phlogopite is explained by the presence of symmetrically arranged inclusions (cf. Art. **342**).

Fig. 474 shows an interesting case of symmetrically arranged inclusions due to chemical alteration. The original mineral, spodumene, from Branchville, Conn., has been altered to a substance apparently homogeneous to the eye, but found under the microscope to have the structure shown in Fig. 474. Chemical analysis proves the base to be albite and the inclosed hexagonal mineral to be a lithium silicate ($LiAlSiO_4$) called eucryptite. It has not yet been identified except in this form.

LITERATURE.

Some of the most important works on the subject of microscopic inclusions are referred to here; for a fuller list of papers reference may be made to the work of Rosenbusch (1873, 1892); also that of Zirkel and others mentioned on p. 4.

Brewster. Many papers, published mostly in the Philosophical Magazine, and the Edinburgh Phil. Journal, from 1822–1856.

Blum, Leonhard, Seyfert, and **Söchting.** Die Einschlüsse von Mineralien in krystallisirten Mineralien. Haarlem, 1854. (Preisschrift.)

Sorby. On the microscopical structure of crystals, etc. Q. J. G. Soc., **14**, 453, 1858 (and other papers).

Sorby and **Butler.** On the structure of rubies, sapphires, diamonds, and some other minerals. Proc. Roy. Soc., No. 109, 1869.

Reusch. Labradorite. Pogg. Ann., **120**, 95, 1863.

Vogelsang. Labradorite. Arch. Néerland., **3**, 32, 1868.

Fischer. Kritische-microscopische mineralogische Studien. Freiburg in Br., 64 pp., 1869; 1te Fortsetzung, 64 pp., 1871; 2te Forts., 96 pp., 1873.

Kosmann. Hypersthene. Jahrb. Min., 532, 1869; 501, 1871.

Schrauf. Labradorite. Ber. Ak. Wien, **60** (1), 996, 1869.

Vogelsang. Die Krystalliten. 175 pp., Bonn, 1875.

Vogelsang and **Geissler.** Ueber die Natur der Flüssigkeitseinschlüsse in gewissen Mineralien. Pogg. Ann., **137**, 56, 257, 1869.

Hartley. Liquid CO_2 in cavities, etc. J. Chem. Soc., **1**, 137; **2**, 237, 1876; **1**, 241; **2**, 271, 1877; also, Proc. Roy. Soc., **26**, 137, 150, 1877.

Gümbel. Enhydros. Ber. Ak. München, **10**, 241, 1880; **11**, 321, 1881.

Hawes. Smoky quartz (CO_2). Am. J. Sc., **21**, 203, 1881.

A. W. Wright. Gases in smoky quartz. Am. J. Sc., **21**, 209, 1881.

CRYSTALLINE AGGREGATES.

247. The greater part of the specimens or masses of minerals that occur may be described as aggregations of imperfect crystals. Many specimens whose structure appears to the eye quite homogeneous, and destitute internally of distinct crystallization, can be shown to be composed of crystalline grains. Under the above head, consequently, are included all the remaining varieties of structure among minerals.

The individuals composing imperfectly crystallized individuals may be:

1. *Columns, or fibers,* in which case the structure is *columnar or fibrous.*
2. *Thin laminæ,* producing a *lamellar* structure.
3. *Grains,* constituting a *granular* structure.

248. Columnar and Fibrous Structure.—A mineral possesses a *columnar* structure when it is made up of slender columns, as some amphibole. When the individuals are flattened like a knife-blade, as in cyanite, the structure is said to be *bladed.*

The structure again is called *fibrous* when the mineral is made up of fibers, as in asbestus, also the satin-spar variety of gypsum. The fibers may or may not be *separable.* There are many gradations between coarse columnar and fine fibrous structures. Fibrous minerals have often a silky luster.

The following are properly varieties of columnar or fibrous structure:

Reticulated: when the fibers or columns cross in various directions and produce an appearance having some resemblance to a net.

Stellated: when they radiate fron a center in all directions and produce star-like forms. Ex. stilbite, wavellite.

Radiated, divergent: when the crystals radiate from a center without producing stellar forms. Ex. quartz, stibnite.

249. Lamellar Structure.—The structure of a mineral is *lamellar* when it consists of plates or leaves. The laminæ may be curved or straight, and thus give rise to the *curved* lamellar and *straight* lamellar structure. Ex. wollastonite (tabular spar), some varieties of gypsum, talc, etc. If the plates are approximately parallel about a common center the structure is said to be *concentric.* When the laminæ are thin and separable, the structure is said to be *foliaceous* or *foliated.* Mica is a striking example, and the term *micaceous* is often used to describe this kind of structure.

250. Granular Structure.—The particles in a granular structure differ much in size. When coarse, the mineral is described as *coarse-granular;* when fine, *fine-granular;* and if not distinguishable by the naked eye, the structure is termed *impalpable.* Examples of the first may be observed in granular crystalline limestone, sometimes called saccharoidal; of the second, in some varieties of hematite; of the last, in some kinds of sphalerite.

The above terms are indefinite, but from necessity, as there is every degree of fineness of structure among mineral species, from perfectly impalpable, through all possible shades, to the coarsest granular. The term *phanero-crystalline* has been used for varieties in which the grains are distinct, and *crypto-crystalline* for those in which they are not discernible, although an indistinct crystalline structure can be proved by the microscope.

Granular minerals, when easily crumbled in the fingers, are said to be *friable.*

251. Imitative Shapes.—The following are important terms used in describing the imitative forms of massive minerals.

Reniform: kidney-shaped. The structure may be radiating or concentric. Ex. hematite.

Botryoidal: consisting of a group of rounded prominences. The name is derived from the Greek *βότρος, a bunch of grapes.* Ex. limonite, chalcedony, prehnite.

Mammillary: resembling the botryoidal, but composed of larger prominences. Ex. malachite.

Globular: spherical or nearly so; the globules may consist of radiating fibers or concentric coats. When attached, as they usually are, to the surface of a rock, they are described as *implanted globules.*

Nodular: in tuberose forms, or having irregular protuberances over the surface.

Amygdaloidal: almond-shaped, applied often to a rock (as diabase) containing almond-shaped or sub-globular nodules.

Coralloidal: like coral, or consisting of interlaced flexuous branchings of a white color, as in the variety of aragonite called *flos ferri.*

Dendritic: branching tree-like, as in crystallized gold. .The term *dendrites* is used for similar forms even when not crystalline, as in the dendrites of manganese oxide, which form on surfaces of limestone or are inclosed in "moss-agates."

Mossy: like moss in form or appearance.

Filiform or *Capillary:* very slender and long, like a thread or hair; consists ordinarily of a succession of minute crystals. Ex. millerite.

Acicular: slender and rigid, like a needle. Ex. stibnite.

Reticulated: net-like. See Art. 248.

Drusy: closely covered with minute implanted crystals. Ex. quartz.

Stalactitic: when the mineral occurs in pendent columns, cylinders, or elongated cones. Stalactites are produced by the percolation of water, holding mineral matter in solution, through the rocky roofs of caverns. The evaporation of the water produces a deposit of the mineral matter, and gradually forms a long pendent cylinder or cone. The internal structure may be imperfectly crystalline and granular, or may consist of fibers radiating from the central column, or there may be a broad cross-cleavage. The most familiar example of stalactites is afforded by calcite. Chalcedony, gibbsite, limonite, and some other species, also present stalactitic forms.

The term ***amorphous*** is used when a mineral has not only no crystalline form or imitative shape, but does not polarize the light even in its minute particles, and thus appears to be destitute wholly of a crystalline structure internally, as most opal. Such a structure is also called *colloid* or jelly-like, from the Greek κόλλα (see p. 6), for glue. The word amorphous is from *ἀ privative*, and μόρφη, shape.

---

252. Pseudomorphous Crystals.—Every mineral species has, when distinctly crystallized, a definite and characteristic form. Occasionally, however, crystals are found that have the form, both as to angles and general habit, of a certain species, and yet differ from it entirely in chemical composition. Moreover, it is often noted in such cases that, though in outward form complete crystals, in internal structure they are granular, or waxy, and have no regular cleavage. Even if they are crystalline in structure the optical characters do not conform to those required by the symmetry of the faces.

Such crystals are called *pseudomorphs*, and their existence is explained by the assumption, often admitting of direct proof, that the original mineral has been changed into the new compound; or it has disappeared through some agency, and its place been taken by another chemical compound to which the form does not belong. In all these cases the new substance is said to be a *pseudomorph after* the original mineral.

Common illustrations of pseudomorphous crystals are afforded by malachite in the form of cuprite, limonite in the form of pyrite, barite in the form of quartz, etc. This subject is further discussed in the chapter on Chemical Mineralogy.

PART II. PHYSICAL MINERALOGY.

253. The PHYSICAL CHARACTERS of minerals fall under the following heads:

I. Characters depending upon *Cohesion* and *Elasticity*—viz., cleavage, fracture, tenacity, hardness, elasticity, etc.

II. *Specific Gravity*, or the *Density* compared with that of water.

III. Characters depending upon *Light*—viz., color, luster, degree of transparency, special optical properties, etc.

IV. Characters depending upon *Heat*—viz., heat-conductivity, change of form and of optical characters with change of temperature, fusibility, etc.

V. Characters depending upon *Electricity* and *Magnetism*.

VI. Characters depending upon the action of the senses—viz., taste, odor, feel.

254. General Relation of Physical Characters to Molecular Structure.—It has been stated on pp. 5, 6 that the geometrical form of a crystallized mineral is the external evidence of the internal molecular structure. A full knowledge in regard to this structure, however, can only be obtained by the study of the various physical characters included in the classes enumerated above.

Of these characters, the specific gravity merely gives indication of the atomic mass of the elements present, and further, of the state of molecular aggregation. The first of these points is illustrated by the high specific gravity of compounds of lead; the second, by the distinction observed, for example, between carbon in the form of the diamond, with a specific gravity of 3·5, and the same chemical substance as the mineral graphite, with a specific gravity of only 2.

All the other characters (except the relatively unimportant ones of Class VI) in general vary according to the direction in the crystal; in other words, they have a definite orientation. For all of them it is true that *directions which are crystallographically identical have like physical characters.*

In regard to the converse proposition—viz., *that in all directions crystallographically dissimilar there may be a variation in the physical characters*, an important distinction is to be made. This proposition holds true for all crystals, so far as the characters of Class I are concerned; that is, those depending upon the cohesion and elasticity, as shown in the cleavage, hardness, the planes of molecular gliding, the etching-figures, etc. It is also true in the case of pyro-electricity and piezo-electricity.

It does *not* apply in the same way with respect to the characters which involve the propagation of light (and radiant heat), the change of volume with change of temperature; further, electric radiation, magnetic induction, etc.

Thus, although it will be shown that the optical characters of crystals are in agreement in general with the symmetry of their form, they do not show all the variations in this symmetry. It is true, for example, that all directions are optically similar in a crystal belonging to any group under the isometric system; but this is obviously not true of its molecular cohesion, as may be shown by the cleavage. Again, all directions in a tetragonal crystal at right angles to the vertical axis are optically similar; but this again is not true of the cohesion. These points are further elucidated under the description of the special characters of each group.

I. CHARACTERS DEPENDING UPON COHESION AND ELASTICITY.

255. Cohesion, Elasticity.—The name *cohesion* is given to the force of attraction existing between the molecules of one and the same body, in consequence of which they offer resistance to any influence tending to separate them, as in the breaking of a solid body or the scratching of its surface.

Elasticity is the force which tends to restore the molecules of a body back into their original position, from which they have been disturbed, as when a body has suffered change of shape or of volume under pressure.

The varying degrees of cohesion and elasticity for crystals of different minerals, or for different directions in the same crystal, are shown in the prominent characters: cleavage, fracture, tenacity, hardness; also in the gliding-planes, percussion-figures or pressure-figures, and the etching-figures.

256. Cleavage.—Cleavage is the tendency of a crystallized mineral to break in certain definite directions, yielding more or less smooth surfaces. It obviously indicates a minimum value of cohesion in the direction of easy fracture—that is, normal to the cleavage-plane itself. The cleavage parallel to the cubic faces of a crystal of galena is a familiar illustration. An amorphous body (p. 6) necessarily can show no cleavage.

As stated in Art. **31**, the consideration of the molecular structure of crystals shows that a cleavage-plane must be a direction in which the molecules are closely aggregated together; while normal to this the distance between successive layers of molecules must be relatively large, and hence this last is the direction of easy separation. It further follows that cleavage can exist only parallel to some possible face of a crystal, and, further, that this must be one of the common fundamental forms. Hence in cases where the choice in the position of the axes is more or less arbitrary the presence of cleavage is properly regarded as showing which planes should be made fundamental. Still again, cleavage is the same in all directions in a crystal which are crystallographically identical.

Cleavage is defined, (1) according to its direction, as cubic, octahedral, rhombohedral, basal, prismatic, etc. Also, (2) according to the ease with which it is obtained, and the smoothness of the surface yielded. It is said to be *perfect* or *eminent* when it is obtained with great ease, affording smooth, lustrous surfaces, as in mica, topaz, calcite. Inferior degrees of cleavage are spoken of as distinct, indistinct or imperfect, interrupted, in traces, difficult. These terms are sufficiently intelligible without further explanation. It may be noticed that the cleavage of a species is sometimes better developed in some of its varieties than in others.

257. Cleavage in the Different Systems.—(1) In the ISOMETRIC SYSTEM, cleavage is *cubic*, when parallel to the faces of the cube; this is the common case, as illustrated by galena and halite. It is also often *octahedral*—that is, parallel to the octahedral faces, as with fluorite and the diamond. Less frequently it is *dodecahedral*, or parallel to the faces of the rhombic dodecahedron, as with sphalerite.

In the TETRAGONAL SYSTEM, cleavage is often *basal*, or parallel to the basal plane, as with apophyllite; also *prismatic*, or parallel to one (or both) of the square prisms, as with rutile and wernerite; less frequently it is *pyramidal*, or parallel to the faces of the square pyramid, as with scheelite.

In the HEXAGONAL SYSTEM, cleavage is usually either *basal*, as with beryl, or *prismatic*, parallel to one of the six-sided prisms, as with nephelite; *pyramidal* cleavage, as with pyromorphite, is rare and imperfect.

In the RHOMBOHEDRAL DIVISION, besides the basal and prismatic cleavages, *rhombohedral* cleavage, parallel to the faces of a rhombohedron, is also common, as with calcite and the allied species.

In the ORTHORHOMBIC SYSTEM, cleavage parallel to one or more of the pinacoids is common. Thus it is *basal* with topaz, and in all three pinacoidal directions with anhydrite. *Prismatic* cleavage is also common, as with barite; in this case the arbitrary position assumed in describing the crystal may make this cleavage parallel to a "horizontal prism," or dome.

In the MONOCLINIC SYSTEM, *clinodiagonal* cleavage, parallel to the clinopinacoid, is common, as with orthoclase, gypsum, heulandite and euclase; also *basal*, as with the micas and orthoclase, or parallel to the orthopinacoid; also *prismatic*, as with amphibole. Less frequently cleavage is parallel to a hemi-pyramid, as with gypsum.

In the TRICLINIC SYSTEM, it is usual and proper to so select the fundamental form as to make the cleavage directions correspond with the pinacoids.

258. In some cases cleavage which is ordinarily not observed may be developed by a sharp blow or by sudden change of temperature. Thus, quartz is usually conspicuously free from cleavage, but a quartz crystal heated and plunged into cold water often shows planes of separation* parallel to both the + and − rhombohedrons and to the prism as well. Similarly, the prismatic cleavage of pyroxene is observed with great distinctness in thin sections, made by grinding, while not so readily noted in large crystals.

When the cleavage is parallel to a closed form—that is, when it is cubic, octahedral, dodecahedral, or rhombohedral (also pyramidal in the tetragonal, hexagonal, and orthorhombic systems)—a solid resembling a crystal may often be broken out from a single crystalline individual, and all the fragments have the same angles. It is, in general, easy to distinguish such a cleavage form, as a cleavage octahedron of fluorite, from a true crystal by the splintery character of the faces of the former.

259. Cleavage and Luster.—The face of a crystal parallel to which there is perfect cleavage often shows a pearly luster (see p. 189), due to the partial separation of the crystal into parallel plates. This is illustrated by the basal plane of apophyllite, the clinopinacoid of stilbite and heulandite. An iridescent play of colors is also often seen, as with calcite, when the separation has been sufficient to produce the prismatic colors by interference.

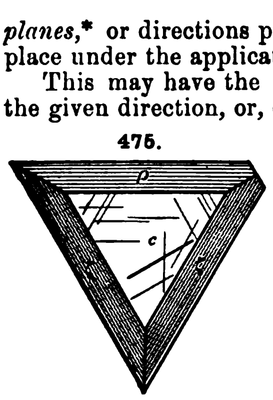
260. Gliding-planes.—Closely related to the cleavage directions in their connection with the cohesion of the molecules of a crystal are the *gliding-*

---

* Lehmann (Zs. Kryst., 11, 608, 1886) and Judd (Min. Mag., 8, 7, 1888) regard these as gliding-planes (see Art. 260).

planes,* or directions parallel to which a slipping of the molecules may take place under the application of mechanical force, as by pressure.

475.



Biotite.

This may have the result of simply producing a separation into layers in the given direction, or, on the other hand, and more commonly, there may be a revolution of the molecules into a new twinning-position, so that *secondary twinning-lamellæ* are formed.

Thus, if a crystal of halite, or rock salt, be subjected to gradual pressure in the direction of a dodecahedral face, a plane of separation is developed normal to this and hence in the direction of another face of the same form. There are six such directions of molecular slipping and separation in a crystal of this substance. Certain kinds of mica of the biotite class often show pseudo-crystalline faces, which are undoubtedly secondary in origin—that is, have been developed by pressure exerted subsequently to the growth of the crystal (cf. Fig. 475).

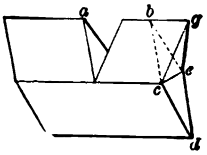
In stibnite, the base, *c* (001), normal to the plane of perfect cleavage, is a gliding-plane. Thus a slipping of the molecules without their separation may be made to take place by pressure in a plane (‖*c*) normal to the direction of perfect cleavage (‖*b*). A slender prismatic crystal supported near the ends and pressed downward by a dull edge is readily bent, or knicked, in this direction without the parts beyond the support being affected.

261. Secondary Twinning.—The other case mentioned in the preceding article, where molecular slipping is accompanied by a half-revolution (180°) of the molecules into a new twinning-position (see p. 118 *et seq*), is well illustrated by calcite. Pressure upon a cleavage-fragment may result in the formation of a number of thin lamellæ in twinning-position to the parent mass, the twinning-plane being the obtuse negative rhombohedron, *e* $(01\bar{1}2)$. Secondary twinning-lamellæ similar to these are often observed in natural cleavage-masses of calcite, and particularly in the grains of a crystalline limestone, as observed in thin sections under the microscope.

Secondary twinning-lamellæ may also be produced (and are often noted in nature) in the case of the triclinic feldspars, pyroxene, barite, etc. A secondary lamellar structure in quartz has been observed by Judd, in which the lamellæ consisted of right-handed and left-handed portions.

By the proper means a complete calcite twin may be artificially produced by pressure. Thus, if a cleavage-fragment of prismatic form, say 6–8 mm. in length and 3–6 mm. in breadth, be placed with the obtuse edge on a firm horizontal support, and pressed by the blade of an ordinary table-knife on the other obtuse edge (at *a*, Fig. 476), the result is that the portion of the crystal lying between *a* and *b* is reversed in position, as if twinned parallel to the horizontal plane $(01\bar{1}2)$. If skillfully done, the twinning surface, *gce*, is perfectly smooth, and the re-entrant angle corresponds exactly with that required by theory.

476.



262. Parting.—The secondary twinning-planes described are often directions of an easy separation—conveniently called *parting*—which may be mistaken for cleavage.† The basal parting of pyroxene is a common example of such pseudo-cleavage; it was long mistaken for cleavage. The basal and rhombohedral $(10\bar{1}1)$ and the less distinct prismatic $(11\bar{2}0)$ parting of corundum; the octahedral parting of magnetite (cf. Fig. 456, p. 136), are other examples.

---

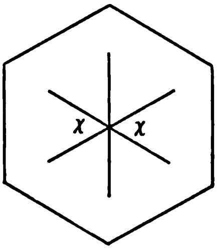
* From the German, *Gleitflächen*.

† The lamellar structure of a massive mineral, without twinning, may also be the cause of a fracture which can be mistaken for cleavage.

An important distinction between cleavage and parting is this: parting can exist only in certain definite planes—that is, on the surface of a twinning-lamella—while the cleavage may take place in *any* plane having the given direction.

263. Percussion-figures.—Immediately connected with the gliding-planes are the figures—called *percussion-figures* [*]—produced upon a crystal section by a blow or pressure with a suitable point. In such cases, the method described serves to develop more or less well-defined cracks whose orientation varies with the crystallographic direction of the surface. Thus upon the cubic face of a crystal of halite a four-rayed, star-shaped figure is produced with arms parallel to the diagonals—that is, parallel to the dodecahedral faces. On an octahedral face a three-rayed star is obtained.

477.



The percussion-figures in the case of the micas have been often investigated, and, as remarked later, they form a means of fixing the true orientation of a cleavage-plate having no crystalline outlines. The figure (Fig. 477) is here a six-rayed star one of whose branches is parallel to the clinopinacoid (*b*), the others approximately parallel to the intersection edges of the prism (*m*) and base (*c*).[†]

Pressure upon a mica plate produces a less distinct six-rayed star, diagonal to that just named; this is called a *pressure-figure* (Germ. *Druckfläche*).

264. Solution-planes.—In the case of many crystals, it is possible to prove the existence of certain directions, or structure-planes, in which chemical action takes place most readily—for example, when a crystal is under great pressure. These directions of chemical weakness have been called *solution-planes*. They often manifest themselves by the presence of a multitude of oriented cavities of crystalline outline (so-called negative crystals) in the given direction.

These solution-planes in certain cases, as shown by Judd, are the same as the directions of secondary lamellar twinning, as is illustrated by calcite. Connected with this is the *schillerization* (see Art. 343) observed in certain minerals in rocks (as diallage, schiller-spar).

265. Etching-figures.—Intimately connected with the general subjects here considered, of cohesion in relation to crystals, are the figures produced by etching on crystalline faces; these are often called *etching-figures*.[‡] This method of investigation, developed particularly by Baumhauer, is of high importance as revealing the molecular structure of the crystal faces under examination, and therefore the symmetry of the crystal itself.

The etching is performed mostly by solvents, as by water in some cases, more generally the ordinary mineral acids, or caustic alkalies, also by steam at a high pressure and hydrofluoric acid; the last is especially powerful in its action, and is used frequently with the silicates. The figures produced are in the majority of cases angular depressions, such as low triangular or quadrilateral pyramids, whose outlines may run parallel to some of the crystalline edges. In some cases the planes produced can be referred to occurring crystallographic faces. They appear alike on similar faces of crystals, and hence serve to distinguish different forms, perhaps in appearance identical, as the two sets of faces in the ordinary double pyramid of quartz; so, too, they reveal the compound twinning-structure common on some crystals, as quartz and aragonite. Further, their form in general corresponds to the symmetry of the group to which the given crystal belongs. They thus reveal the trapezohedral symmetry of quartz and the difference between a right-handed and left-handed crystal (Figs. 478, 479); the distinction between calcite and dolomite (Figs. 482, 483); the distinctive character of apatite, pyromorphite, etc.; the hemimorphic symmetry of calamine and nephelite (cf. Fig. 220, p. 73), etc.; they also prove by their form the monoclinic crystallization of muscovite and other micas (Fig. 481).

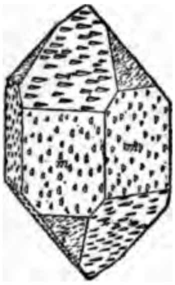
---

[*] From the German, *Schlagfiguren*. The percussion-figures are best obtained if the crystal plate under investigation be supported upon a hard cushion and a blow be struck with a light hammer upon a steel rod the slightly rounded point of which is held firmly against the surface.

[†] Cf. Walker, Am. J. Sc., 2, 5, 1896, and G. Friedel, Bull. Soc. Min., 19, 18, 1896. Walker found the angle opposite *b* (010) (χ in Fig. 477) to be 53° to 56° for muscovite, 59° for lepidolite, 60° for biotite, and 61° to 63° for phlogopite.

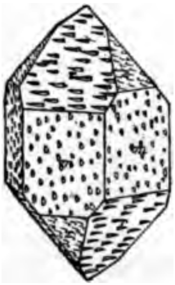
[‡] From the German, *Aetzfiguren*.

478.



Quartz, right-handed crystal.

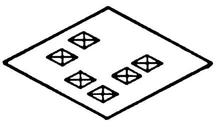
479.



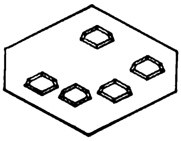
Quartz, left-handed crystal.

Fig. 480 shows the etching-figures formed on a basal plane (cleavage) of topaz by fused caustic potash; Fig. 481, those on a cleavage-plate of muscovite by hydrofluoric acid; Fig. 482, upon a rhombohedral face of calcite, and Fig. 483, on one of dolomite by dilute hydrochloric acid.

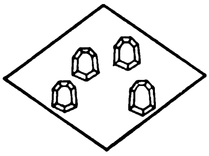
480.



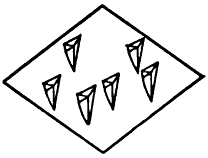
481.



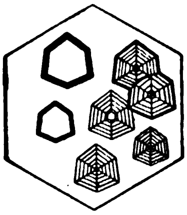
482.



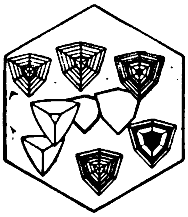
483.



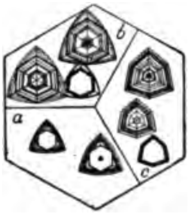
484.



485.



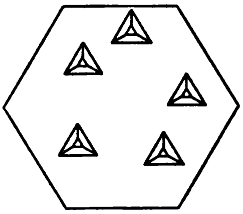
486.



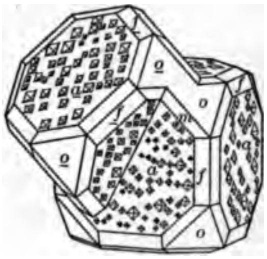
The shape of the etching-figures may vary with the same crystal with the nature of the solvent employed, though their symmetry remains constant. For example, Fig. 484 shows the figures obtained with spangolite by the action of sulphuric acid, Fig. 485 by the same diluted, and Fig. 486 by hydrochloric acid of different degrees of concentration.

Of the same nature as the etching-figures artificially produced, in their relation to the symmetry of the crystal, are the markings often observed on the natural faces of crystals. These are sometimes secondary, caused by a natural etching process, but are more often an irregularity in the crystalline development of the crystal. The inverted triangular depressions often seen on the octahedral faces of diamond crystals are an example. Fig. 487 shows natural depressions, rhombohedral in character, observed on corundum crystals from Montana (Pratt). Fig. 488 shows a twin crystal of fluorite with natural etching-figures (Pirsson); these are minute pyramidal depressions whose sides are parallel to the faces of the trapezohedron (311).

487.



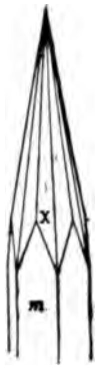
488.



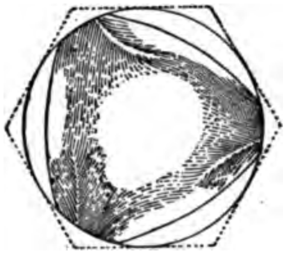
266. Corrosion Forms.—If the etching process spoken of in the preceding article—whether natural or artificial—is continued, the result may be to destroy the original crystalline surface and to substitute for it perhaps a multitude of minute elevations, more or less distinct; or, further, new faces may be developed, the crystallographic position of which can often be determined, though the symbols may be complex. This is illustrated by Fig. 489 of beryl; here *x* is the berylloid $(36\cdot24\cdot\overline{60}\cdot5)$. The mere loss of water in some cases produces certain corrosive forms (see Pape, literature).

Penfield subjected a sphere of quartz (from a simple right-handed individual) to the prolonged action of hydrofluoric acid. It was found that it was attacked rapidly in the direction of the vertical axis, but barely at all at the + extremities of the axes. Figs. 490, 491 show the form remaining after the sphere had been etched for seven weeks; Fig. 490 is a basal view; Fig. 491, a front view; the circle shows the original form of the sphere, the dotted hexagon the position of the axes. Compare also the results of Meyer on calcite (see literature, p. 155).

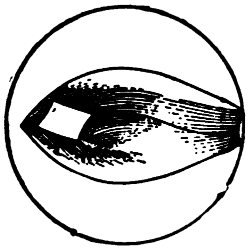
489.



490.



491.



267. Fracture.—The term *fracture* is used to define the form or kind of surface obtained by breaking in a direction other than that of cleavage in crystallized minerals, and in any direction in massive minerals. When the cleavage is highly perfect in several directions, as the rhombohedral cleavage of calcite, fracture is often not readily obtainable.

Fracture is defined as:

(*a*) *Conchoidal;* when a mineral breaks with curved concavities, more or less deep. It is so called from the resemblance of the concavity to the valve of a shell, from concha, *a shell.* This is well illustrated by obsidian, also by flint. If the resulting forms are small, the fracture is said to be *small-conchoidal;* if only partially distinct, it is *subconchoidal.*

(*b*) *Even;* when the surface of fracture, though rough with numerous small elevations and depressions, still approximates to a plane surface.

(*c*) *Uneven;* when the surface is rough and entirely irregular; this is true of most minerals.

(*d*) *Hackly;* when the elevations are sharp or jagged; broken iron.

Other terms also employed are *earthy, splintery,* etc.

268. Hardness.—The *hardness* of a mineral is measured by the resistance which a smooth surface offers to abrasion. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or by a file or knife.

In minerals there are all grades of hardness, from that of talc, impressible by the finger-nail, to that of the diamond. To give precision to the use of this character, a ***scale of hardness*** was introduced by Mohs.[*] It is as follows:

1. *Talc.*
2. *Gypsum.*
3. *Calcite.*
4. *Fluorite.*
5. *Apatite.*
6. *Orthoclase.*
7. *Quartz.*
8. *Topaz.*
9. *Sapphire.*
10. *Diamond.*

Crystalline varieties with smooth surfaces should be taken so far as possible.

If the mineral under examination is scratched by the knife-blade as easily as calcite its hardness is said to be 3; if less easily than calcite and more so than fluorite its hardness is 3·5. In the latter case the mineral in question would be scratched by fluorite but would itself scratch calcite. It need hardly be added that great accuracy is not attainable by the above methods, though, indeed, for purposes of the determination of minerals exactness is quite unnecessary.

It should be noted that minerals of grade 1 have a greasy feel to the hand; those of grade 2 are easily scratched by the finger-nail; those of grade 3 are rather readily cut, as by a knife; of grade 4, scratched rather easily by the knife; grade 5, scratched with some difficulty; grade 6, barely scratched by a knife, but distinctly by a file—moreover, they also scratch ordinary glass. Minerals as hard as quartz (H. = 7), or harder, scratch glass readily but are little touched by a file; the few species belonging here are enumerated in Appendix B; they include all the gems.

269. Sclerometer.—Accurate determinations of the hardness of minerals can be made in various ways, one of the best being by use of an instrument called a *sclerometer.* The mineral is placed on a movable carriage, with the surface to be experimented upon horizontal; this is brought in contact with a steel point (or diamond point), fixed on a support above; the weight is then determined which is just sufficient to move the carriage and produce a scratch on the surface of the mineral.

---

[*] The interval between 2 and 3, and 5 and 6, in the scale of Mohs, being a little greater than between the other numbers, Breithaupt proposed a scale of *twelve* minerals; but the scale of Mohs is now universally accepted.

By means of such an instrument the hardness of the different faces of a given crystal has been determined in a variety of cases. It has been found that different faces of a crystal (*e.g.*, cyanite) differ in hardness, and the same face may differ as it is scratched in different directions. In general, differences in hardness are noted only with crystals which show distinct cleavage; the hardest face is that which is intersected by the plane of most complete cleavage. Further, of a single face, which is intersected by cleavage-planes, the direction perpendicular to the cleavage-direction is the softer, those parallel to it the harder.

This subject has been investigated by Exner (p. 155), who has given the form of the *curves of hardness* for the different faces of many crystals. These curves are obtained as follows: the least weight required to scratch a crystalline surface in different directions, for each 10° or 15°, from 0° to 180°, is determined with the sclerometer; these directions are laid off as radii from a center, and the length of each is made proportional to the weight fixed by experiment—that is, to the hardness thus determined; the line connecting the extremities of these radii is the curve of hardness for the given face.

The following table gives the results obtained[*] (see literature) in comparing the hardness of the minerals of the scale from corundum, No. 9, taken as 1000, to gypsum, No. 2. Pfaff used the method of boring with a standard point, the hardness being determined by the number of rotations; Rosiwal used a standard powder to grind the surface, Jaggar employed his micro-sclerometer, the method being essentially a modification of that of Pfaff. By means of this instrument he is able to test the hardness of the minerals present in a thin section under the microscope. Measurements of absolute hardness have also been made by Auerbach.

	Pfaff, 1884.	Rosiwal, 1892.	Jaggar, 1897.
9. Corundum	1000	1000	1000
8. Topaz	459	138	152
7. Quartz	254	149	40
6. Orthoclase	191	28·7	25
5. Apatite	53·5	6·20	1·23
4. Fluorite	37 3	4·70	·75
3. Calcite	15·3	2·68	·26
2. Gypsum	12·03	·34	·04

270. Relation of Hardness to Chemical Composition.—Some general facts of importance can be stated[†] in regard to the connection between the hardness of a mineral and its chemical composition.

1. Compounds of the heavy metals, as silver, copper, mercury, lead, etc., are *soft*, their hardness seldom exceeding 2·5 to 3.

Among the compounds of the common metals, the sulphides (arsenides) and oxides of iron (also of nickel and cobalt) are relatively *hard* (*e.g.*, for pyrite H. = 6 to 6·5; for hematite H. = 6, etc.); here belong also columbite, iron niobate, tantalite, iron tantalate, wolframite, iron tungstate.

2. The sulphides are mostly relatively soft (except as noted in 1), also most of the carbonates, sulphates, and phosphates.

3. Hydrous salts are relatively soft. This is most distinctly shown among the silicates—*e.g.*, compare the feldspars and zeolites.

4. The conspicuously hard minerals are found chiefly among the oxides and silicates; many of them are compounds containing aluminium—*e.g.*, corundum, diaspore, chrysoberyl, and many alumino-silicates. Outside of these the borate, boracite, is hard (H. = 7); also iridosmine.

On the relation of hardness to specific gravity, see Art. 280.

---

[*] The numbers are here given as tabulated by Jaggar.

[†] See further in Appendix B.

271. Practical Suggestions.—Several points should be regarded in the trials of hardness:

(1) If the mineral is slightly altered, as is often the case with corundum, garnet, etc., the surface may be readily scratched when this would be impossible with the mineral itself; a trial with an edge of the latter will often give a correct result in such a case.

(2) A mineral with a granular surface often appears to be scratched when the grains have been only torn apart or crushed.

(3) A relatively soft mineral may leave a faint white ridge on a surface, as of glass, which can be mistaken for a scratch if carelessly observed.

(4) A crystal, as of quartz, is often slightly scratched by the edge of another of the same species and like hardness.

(5) The scratch should be made in such a way as to disfigure the specimen as little as possible.

272. Tenacity.—Minerals may be either brittle, sectile, malleable, or flexible.

(*a*) *Brittle;* when parts of a mineral separate in powder or grains on attempting to cut it, as calcite.

(*b*) *Sectile;* when pieces may be cut off with a knife without falling to powder, but still the mineral pulverizes under a hammer. This character is intermediate between brittle and malleable, as gypsum.

(*c*) *Malleable;* when slices may be cut off, and these slices flattened out under a hammer; native gold, native silver.

(*d*) *Flexible;* when the mineral will bend without breaking, and remain bent after the bending force is removed, as talc.

The tenacity of a substance is properly a consequence of its elasticity.

273. Elasticity.—The elasticity of a solid body expresses at once the resistance which it makes to a change in shape or volume, and also its tendency to return to its original shape when the deforming force ceases to act. If the *limit of elasticity* is not passed, the change in molecular position is proportional to the force acting, and the former shape or volume is exactly resumed; if this limit is exceeded, the deformation becomes permanent, a new position of molecular equilibrium having been assumed; this is shown in the phenomena of gliding-planes and secondary twinning, already discussed. The magnitude of the elasticity of a given substance is measured by the *coefficient of elasticity*, or, better, the coefficient of restitution. This is defined as the relation, for example, between the elongation of a bar of unit section to the force acting to produce this effect; similarly of the bending or twisting of a bar. The subject was early investigated acoustically by Savart; in recent years, Voigt and others have made accurate measures of the elasticity of many substances and of the crystals of the same substance in different directions. The elasticity of an amorphous body is the same in all directions, but it changes in value with change of crystallographic direction in all crystals.

The distinction between *elastic* and *inelastic* is often made between the species of the mica group and allied minerals. Muscovite, for example, is described as "highly elastic," while phlogopite is much less so. In this case it is not true in the physical sense that muscovite has a high value for the coefficient of elasticity; its peculiarity lies rather in the fact that its elasticity is displayed through unusually wide limits.

LITERATURE.

Hardness.

Frankenheim. See references on p. 22.
Seebeck. Sklerometer. Programm d. Cöln Realgymnasiums, 1833.
Franz. Pogg., **80**, 37, 1850.
Grailich u. Pekárek. Ber. Ak. Wien, **13**, 410, 1854.

Pfaff. Mesosklerometer. Ber. Ak. München, **13**, 55, 1883.

Sohncke. Halite. Pogg., **137**, 177, 1869.

Exner. Ueber die Härte der Krystallflächen, 166 pp. Vienna, 1873 (Preisschrift, Wiener. Akad.).

Auerbach. Wied. Ann., **43**, 61, 1891; **45**, 262, 277, 1892; **58**, 357, 1896.

Rosiwal. Verh. G. Reichs., 475, 1896.

T. A. Jaggar, Jr. Microsclerometer. Am. J. Sc., **4**, 399, 1897.

Etching-figures, etc.

Daniell. Quart. J. Science, **1**, 24, 1816.

Leydolt. Agate, aragonite, quartz. Ber. Ak. Wien, **15**, 59, 1855; **19**, 10, 1856.

Pape. Verwitterungs-ellipsoid wasserhaltiger Krystalle. Pogg. Ann., **124**, 329; **125**, 513, 1865.

Hirschwald. Quartz. Pogg. Ann., **137**, 548, 1869.

Baumhauer. Many important researches. Pogg. Ann., **138**, 563, 1869; **139**, 349; **140**, 271. 1870; **145**, 459, 1872; **150**, 619, 1873; **153**, 75, 621, 1874; also Ber. Ak. München, 1874–75. Further, Jahrb. Min., 1876 *et seq.*, and Zs. Kryst., 1877 *et seq.* Finally the following work: Die Resultate der Aetzmethode in der krystallographischen Forschung, etc., with 12 photo-plates, Leipzig, 1894.

Rose. Diamond (effect of slow combustion). Pogg. Ann., **148**, 497, 1873.

Exner. Lösungsfiguren, etc. Ber. Ak. Wien, **69** (2), 6, 1874.

Klocke. Alum. Zs. Kryst., **2**, 126, 1878.

Sohncke. Verwitterungs-ellipsoid. Zs. Kryst., **4**, 225, 1879.

Tschermak. Calcite, dolomite, etc. Min. petr. Mitth., **4**, 99, 1881.

Becke. Sphalerite. Min. petr. Mitth., **5**, 457, 1882. Galena, ibid., **6**, 237, 1884.

Meyer. Calcite. Jahrb. Min., **1**, 74, 1883.

Ebner. Calcite, aragonite, etc. Ber. Ak. Wien, **89** (2), 368, 1884; **91** (2), 760, 1885.

Hamberg. Calcite. Geol. För. Förh., **17**, 53, 1885.

Penfield. Quartz. Trans. Conn. Acad., **8**, 158, 1889.

Molengraaff. Quartz. Zs. Kr., **14**, 173, 1888; **17**, 137, 1889.

Traube. Cuprite, wulfenite, beryl, etc. Jahrb. Min., Beil.-Bd., **10**, 454, 1896.

T. L. Walker. Tourmaline, rhodonite, feldspars, etc. Am. J. Sc., **5**, 176, 1898.

Gliding-planes, Secondary Twinning, etc.

Reusch. "Körnerprobe," halite, calcite. Pogg. Ann., **132**, 441, 1867. Mica, ibid., **136**, 130, 632, 1869. Gypsum, ibid., p. 135. Ber. Ak., Berlin, 440, 1873.

Bauer. Mica, etc. Pogg. Ann., **138**, 337, 1869; Zs. G. Ges., **26**, 137, 1874. Galena, Jb. Min., **1**, 138, 1882.

Baumhauer. Calcite. Zs. Kr., **3**, 588, 1879.

Mügge. Calcite, augite, stibnite, etc. Jb. Min., **1**, 32, 1883; **2**, 13, 1883. Also ibid., **1**, 71, 1898.

J. W. Judd. Solution-planes, etc. Q. J. G. Soc., **41**, 374, 1885; Min. Mag., **7**, 81, 1887. Structure planes of corundum, Min. Mag., **11**, 49, 1895.

Voigt. See below.

Elasticity.

Savart. Ann. Ch. Phys., **40**, 1, 113, 1829; also in Pogg. Ann., **16**, 206, 1829.

Neumann. Pogg. Ann., **31**, 177, 1834.

Ångström. Pogg. Ann., **86**, 206, 1852.

Baumgarten. Calcite. Pogg. Ann., **152**, 369, 1874.

Groth. Halite. Pogg. Ann., **157**, 115, 1876.

Coromilas. Gypsum, mica. Inaug. Diss., Tübingen, 1877 (Zs. Kryst., **1**, 407, 1877).

Reusch. Ice. Wied. Ann., **9**, 329, 1880.

Klang. Fluorite. Wied. Ann., **12**, 321, 1881.

Koch. Halite, sylvite. Wied. Ann., **18**, 325, 1883.

Beckenkamp. Alum. Zs. Kryst., **10**, 41, 1885.

Voigt. Pogg. Ann., Erg.-Bd., **7**, 1, 177, 1876. Wied. Ann., **38**, 573, 1889. Calcite, **39**, 412, 1890. Dolomite, ibid., **40**, 642, 1890. Tourmaline, ibid., **41**, 712, 1890; **44**, 168, 1891. Also papers in Nachr. Ges. Wiss. Göttingen.

II. SPECIFIC GRAVITY OR RELATIVE DENSITY.

274. Definition of Specific Gravity.—The specific gravity of a mineral is the ratio of its density* to that of water at 4° C. (39·2° F.). This relative density may be learned in any case by comparing the ratio of the weight of a certain volume of the given substance to that of an equal volume of water; hence the specific gravity is often defined as: *the weight of the body divided by the weight of an equal volume of water.*

The statement that the specific gravity of graphite is 2, of corundum 4, of galena 7·5, etc., means that the densities of the minerals named are 2, 4, and 7·5, etc., times that of water; in other words, as familiarly expressed, any volume of them, a cubic inch for example, weighs 2 times, 4 times, 7·5 times, etc., as much as a like volume, a cubic inch, of water.

Strictly speaking, since the density of water varies with its expansion or contraction under change of temperature, the comparison should be made with water at a fixed temperature, namely 4° C. (39·2° F.), at which it has its maximum density. If made at a higher temperature, a suitable correction should be introduced by calculation. Practically, however, since a high degree of accuracy is not often called for, and, indeed, in many cases is impracticable to attain in consequence of the nature of the material at hand, in the ordinary work of obtaining the specific gravity of minerals the temperature at which the observation is made can safely be neglected. Common variations of temperature would seldom affect the value of the specific gravity to the extent of one unit in the third decimal place.

For the same reason, it is not necessary to take into consideration the fact that the observed weight of a fragment of a mineral is less than its true weight by the weight of air displaced.

Where the nature of the investigation calls for an *accurate* determination of the specific gravity (*e.g.*, to four decimal places), no one of the precautions in regard to the purity of material, exactness of weight-measurement, temperature, etc., can be neglected.† The accurate values spoken of are needed in the consideration of such problems as the specific volume, the relation of molecular volume to specific gravity, and many others. Some of these have been discussed by Schröder, Hunt, also (for salts) by Playfair and Joule, etc.

275. Determination of the Specific Gravity by the Balance.—The direct comparison by weight of a certain volume of the given mineral with an equal volume of water is not often practicable. By making use, however, of a familiar principle in hydrostatics, viz., that a solid immersed in water, in consequence of the buoyancy of the latter, loses in weight an amount which is equal to the weight of an equal volume of the water (that is, the volume it displaces)—the determination of the specific gravity becomes a very simple process.

The weight of the solid in the air (w) is first determined in the usual manner; then the weight in water is found (w'); the difference between these weights—that is, the loss by immersion ($w - w'$)—is the weight of a volume of water equal to that of the solid; finally, the quotient of the first weight (w) by that of the equal volume of water as determined ($w - w'$) is the specific gravity (G).

---

* The *density* of a body is strictly *the mass of the unit volume.* Thus if a cubic centimeter of water (at its maximum density, 4° C. or 39·2° F.) is taken as the unit of mass, the density of any body—as gold—is given by the number of grams of mass (about 19) in a cubic centimeter; in this case the same number, 19, gives the relative density or specific gravity. If, however, a pound is taken as the unit of mass, and the cubic foot as the unit of volume, the mass of a cubic foot of water is 62·5 lbs., that of gold about 1188 lbs., and the specific gravity is the ratio of the second to the first, or, again, 19.

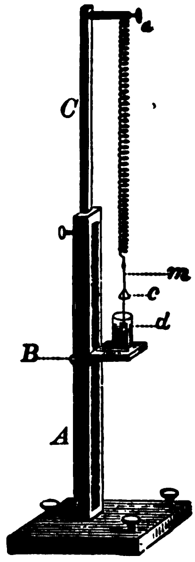
† Cf. Earl of Berkeley in Min. Mag., 11, 64, 1895.

Hence,

$$G = \frac{w}{w - w'}.$$

A common method of obtaining the specific gravity of a firm fragment of a mineral is as follows: First weigh the specimen accurately on a good chemical balance. Then suspend it from one pan of the balance by a horse-hair, silk thread, or, better still, by a fine platinum wire, in a glass of water conveniently placed beneath, and take the weight again with the same care; then use the results as above directed. The platinum wire may be wound around the specimen, or where the latter is small it may be made at one end into a little spiral support.

492.



276. The Jolly Balance.—Instead of using an ordinary balance and determining the actual weight, the spiral balance of Jolly, shown in Fig. 492, may be conveniently employed; this is also suitable when the mineral is in the form of small grains. The mineral is first placed on the glass pan c, and the amount that the spring is stretched noted by the scale number (N_1), opposite to which the index at m comes to rest (the eye sees the reflection in the mirror and thus avoids error by parallax). If from N_1 be subtracted the number n, expressing the amount to which the scale is stretched by the weight of spring and pans alone, the difference will be proportional to the weight of the mineral. Next, the mineral is placed in the lower pan, d, immersed in the water, and again the corresponding scale number, N_2, read. The difference between these readings ($N_1 - N_2$) is a number proportional to the loss of weight in water. The specific gravity is then

$$G = \frac{N_1 - n}{N_1 - N_2}.$$

It is obviously necessary to have the wires supporting the lower pan immersed to the same depth in the case of each of the three determinations. If care is taken the specific gravity can be obtained accurate to two decimal places.

277. Pycnometer.—If the mineral is in the form of grains or small fragments, the specific gravity may be obtained by use of the *pycnometer*. This is a small bottle (Fig. 493) having a stopper which fits tightly and ends in a tube with a very fine opening. The bottle is filled with distilled water, the stopper inserted, and the overflowing water carefully removed with a soft cloth. It is now weighed, and also the mineral whose density is to be determined. The stopper is then removed and the mineral in powder or in small fragments inserted with care, so as not to introduce air-bubbles.* The water which overflows on replacing the stopper is the amount of water displaced by the mineral. The weight of the pycnometer with the inclosed mineral is determined, and the weight of the water lost is obviously the difference between this last weight and that of the bottle and mineral together, as first determined.

---

* It is difficult to prevent the presence of air-bubbles, and hence it is often necessary, in order to insure accuracy, to place the bottle under an air-pump and exhaust the air.

The specific gravity of the mineral is equal to its weight alone divided by the weight of the equal volume of water thus determined. Where this method is followed with sufficient care, especially avoiding any change of temperature in the water, the results may be highly accurate.

If the mineral forms a porous mass, it may be first reduced to powder, but it is to be noted that it has been shown by Rose that chemical precipitates have uniformly a higher density than belongs to the same substance in a less finely divided state. This increase of density also characterizes, though to a less extent, a mineral in a fine state of mechanical subdivision. It is explained by the condensation of the water on the surface of the powder.

493.

278. Use of Liquids of High Density.—It is often found convenient both in the determination of the specific gravity and in the mechanical separation of fragments of different specific gravities (*e.g.*, to obtain pure material for analysis, or again in the study of rocks) to use a liquid of high density—that is, a so-called *heavy solution.* One of these is the solution of mercuric iodide in potassium iodide, called the Sonstadt solution or Thoulet solution. When made with care* it has a maximum density of nearly 3·2, which by dilution may be lowered at will.

A second solution, often employed, is the *Klein solution*, the borotungstate of cadmium, having a maximum density of 3·6. This again may be lowered at will by dilution, observing certain necessary precautions. Still a third solution of much practical value is that proposed by Brauns, methyl iodide, which has a specific gravity of 3·324. A number of other solutions, more or less practical, have also been suggested (see papers referred to in the literature on p. 160, which also give the necessary directions for the use of the liquids). When one of these liquids is to be used for the determination of the specific gravity of fragments of a certain mineral it must be diluted until the fragments just float and the specific gravity then obtained, most conveniently by the Westphal balance (Art. 279).

When, on the other hand, the liquid is to be used for the separation of the fragments of two or more minerals mixed together, the material is first reduced to the proper degree of fineness, the dust and smallest fragments being sifted out, then it is introduced into the solution and this diluted until one constituent after another sinks and is removed. For the convenient application of this method a suitable tube is called for and certain precautions must be observed; compare the papers noted in the literature (p. 160), especially one by Penfield.

279. Westphal's Balance.—The Westphal balance is conveniently used to determine the specific gravity of a liquid, and hence of a mineral when a heavy solution is employed (Art. 278). It consists essentially of a graduated steelyard arm, upon which the weights, in the form of riders, are placed. These must be so adjusted that the sinker is freely suspended in the given liquid while the index at the end points to the zero of the scale and shows that the arm is horizontal (cf. Rosenbusch, Mikr. Phys. Min., p. 246). The graduation usually allows of the specific gravity being read off directly without calculation.

280. Relation of Density to Hardness, Chemical Composition, etc.—The density, or specific gravity, of a solid depends, first, upon the nature of the chemical substances which it contains, and, second, upon the state of molecular aggregation.

Thus, as an illustration of the first point, all lead compounds have a high density (G. = about 6), since lead is a heavy metal, or, chemically expressed, has a high atomic weight (206·4) Similarly, barium sulphate, barite, has a specific gravity of 4·5, while for

---

† See the directions by Goldschmidt, reference on p. 160.

calcium sulphate or anhydrite the value is only 2·95 (at. weight for barium 137, for calcium about 40).

On the other hand, while aluminium is a metal of low density (G. = 2·5 and atomic weight = 27), its oxide, corundum, has a remarkably *high* density (G. = 4) and is also very hard (H. = 9). Again, carbon (at. weight = 12) has a high density in the diamond (G. = 3·5) and low in graphite (G. = 2); also, the first is hard (H. = 10), the second soft (H. = 1·5). In these and similar cases the high density signifies great molecular aggregation, and hence it is natural that it should be accompanied by great hardness and resistance to the attack of acids.

As bearing upon this point, it is to be noted that the density of many substances is altered by fusion. Again, the same mineral in different states of molecular aggregation may differ (but only slightly) in density. Furthermore, minerals having the same chemical composition have sometimes different densities, corresponding to the different crystalline forms in which they appear. Thus in the case of calcium carbonate ($CaCO_3$), calcite has G. = 2·7, aragonite has G. = 2·9.

281. Average Specific Gravities.—It is to be noted that among minerals of UNMETALLIC LUSTER the *average* specific gravity ranges from 2·6 to 3. Here belong quartz (2·66), calcite (2·7), the feldspars (2·6–2·75), muscovite (2·8). A specific gravity of 2·5 or less is *low*, and is characteristic of soft minerals, and often those which are hydrous (*e.g.*, gypsum, G. = 2·3). The common species fluorite, tourmaline, apatite, vesuvianite, amphibole, pyroxene, and epidote lie just above the limit given, namely, 3·0 to 3·5. A specific gravity of 3·5 or above is relatively *high*, and belongs to hard minerals (as corundum, see Art. **280**), or to those containing a heavy metal, as compounds of strontium, barium, also iron, tungsten, copper, silver, lead, mercury, etc.

With minerals of METALLIC LUSTER, the average is about 5 (here belong pyrite, hematite, etc.), while if below 4 it is relatively low (graphite 2, stibnite 4·5); if 7 or above, relatively high (as galena, 7·5).

Tables of minerals arranged according to their specific gravity are given in Appendix B.

282. Constancy of Specific Gravity.—The specific gravity of a mineral species is a character of fundamental importance, and is highly constant for different specimens of the same species, if pure, free from cavities, solid inclusions, etc., and if essentially constant in composition. In the case of many species, however, a greater or less variation exists in the chemical composition, and this at once causes a variation in specific gravity. The different kinds of garnet illustrate this point; also the various minerals intermediate between the tantalate of iron (and manganese) and the niobate, varying from G. = 7·3 or above to G. = 5·3.

283. Practical Suggestions.—It should be noted that the determination of the specific gravity has little value unless the fragment taken is pure and is free from impurities, internal and external, and not porous. Care must be taken to exclude air-bubbles, and it will often be found well to moisten the surface of the specimen before inserting it in the water, and sometimes boiling (or the use of the air-pump) is necessary to free it from air. If it absorbs water this latter process must be allowed to go on till the substance is fully saturated. No *accurate* determinations can be made unless the changes of temperature are rigorously excluded and the actual temperature noted.

In a mechanical mixture of two constituents in known proportions, when the specific gravity of the whole and of one are known, that of the other can be readily obtained. This method is often important in the study of rocks.

It is to be noted that the hand may be soon trained to detect a difference of specific gravity, if like volumes are taken, even in a small fragment—thus the difference between calcite or albite and barite, even the difference between a small diamond and a quartz crystal, can be detected.

LITERATURE.—*Specific Gravity.*

General:

Beudant. Pogg. Ann., **14**, 474, 1828.
Jenzsch. Pogg. Ann., **99**, 151, 1856.
Jolly. Ber. Ak. München, 1864, 162.
Gadolin. Pogg., **106**, 213, 1859.
G. Rose. Pogg. Ann., **73**, 1; **75**, 403, 1848.
Scheerer. Pogg. Ann., **67**, 120, 1846.
Schröder. Pogg. Ann., **106**, 226, 1859. Jahrb. Min., **561**, **932**, 1873; **399**, 1874, etc.
Tschermak. Ber. Ak. Wien, **47** (1), 292, 1863.
Websky. Die Mineralien nach den für das specifische Gewicht derselben angenommenen und gefundenen Werthen. 170 pp. Breslau, 1868.

Use of Heavy Solutions, etc.:

Sonstadt. Chem. News, **29**, 127, 1874.
Thoulet. Bull. Soc. Min., **2**, 17, 189, 1879.
Bréon. Bull. Soc. Min., **3**, 46, 1880.
Goldschmidt. Jb. Min., Beil.-Bd., **1**, 179, 1881.
D. Klein. Bull. Soc. Min., **4**, 149, 1881.
Rohrbach. Jb. Min., **2**, 186, 1883.
Gisevius. Inaug. Diss., Bonn, 1883.
Brauns. Jb. Min., **2**, 72, 1886; **1**, 213, 1888.
Retgers. Jb. Min., **2**, 185, 1889.
Salomon. Jb. Min., **2**, 214, 1891.
Penfield. Am. J. Sc., **50**, 446, 1895.

III. CHARACTERS DEPENDING UPON LIGHT.

GENERAL PRINCIPLES OF OPTICS.

284. Before considering the optical characters of minerals in general, and more particularly those that belong to the crystals of the different systems, it is desirable to review briefly some of the more important principles of optics upon which the phenomena in question depend.

For a fuller discussion of the optics of crystals, special reference is made to the works of Groth, Liebisch, Mallard, and Rosenbusch (and translation by Iddings) mentioned on pp. 2 and 4; also to the various advanced text-books of Physics. The methods of investigation, with the results of the examination of many species, are given in the admirable memoirs by Des Cloizeaux in Ann. Mines, **11**, 261–342, 1857; **14**, 339–420, 1858; **6**, 557–595, 1864. Also his Nouvelles Recherches, etc., 222 pp., 1867. Early observations were also published by Grailich (Vienna, 1850) and by Grailich and von Lang (Ber. Ak. Wien, **27**, 3, 1857; **32**, 43, 1858; **33**, 369, 1858). References to many important papers in special subjects are given later.

285. Nature of Light.—The propagation of light from a luminous body, as the sun or a candle-flame, is believed to be accomplished by a very rapid wave-motion * in the medium called the *luminiferous ether*, which, it is assumed, pervades all space as well as all material bodies.

286. The Ether.—The assumption of the medium called the ether is necessary, since without this it is impossible to explain the transmission of light through space where no ordinary medium (as the air) is present. Furthermore, as the velocity of light even within solid media, though less than that in a vacuum or in air, is still enormously rapid, it is inconceivable that it should be propagated by the molecules of the body; hence the assumption, otherwise verified, that the ether pervades all material bodies. The properties of the ether,† however, are modified by the molecular structure of the given body, as is proved by the fact that the velocity of light varies with the chemical nature of the substance, and also in certain cases with the direction in the given crystallized medium as corresponding to its particular molecular structure.

---

* It is now generally accepted that light is an electro-magnetic phenomenon and that the nature of the periodic motion in the ether by which light is propagated is the same as that involved in the transmission of electric waves produced, for example, by a very rapid oscillatory electric discharge between two spark-knobs. In fact these electric waves have been shown to travel with the same velocity as light-waves, and to exhibit like phenomena of reflection, refraction, polarization, etc.; hence they are believed to differ from light-waves only in their much greater length. For the purposes of the present work, however, light-waves are treated of as if a mechanical phenomenon, but all assumption of variations of the "elasticity of the ether" in crystals as an explanation of the observed variation of light-velocity is avoided.

† Reference is made to an article by Clerk Maxwell in the *Encyclopedia Britannica* for a discussion of the general properties of the luminiferous ether.

287. Wave-motion in General.—A familiar example of wave-motion is given by the series of concentric waves which on a surface of smooth water go out from a center of disturbance, as the point where a pebble has been dropped in. These surface-waves are propagated by a motion of the water-particles which is *transverse* to the direction in which the waves themselves travel; this motion is given from each particle to the next adjoining, and so on. Thus the particles of water at any one spot oscillate up and down,* while the wave moves on as a circular ridge of water of constantly increasing diameter, but of diminishing height. The ridge is followed by a valley, indeed both together properly constitute a wave in the physical sense. This compound wave is followed by another wave and another, until the original impulse has exhausted itself.

Another familiar kind of wave-motion is illustrated by the sound-waves which in the free air travel outward from a sonorous body in the form of concentric spheres. Here the actual motion of the layers of air is forward and back—that is, in the direction of propagation of the sound—and the effect of the transfer of this impulse from one layer to the next is to give rise alternately to a condensed and rarefied shell of air, which together constitute a sound-wave and which expand in spherical waves of constantly decreasing intensity (since the mass of air set in motion continually increases). Sound-waves, as of the voice, may be several feet in length, and they travel at a rate of 1120 feet per second at ordinary temperatures.

288. It is important to understand that in both the cases mentioned, as in every case of free wave-motion, each point on a given wave may be considered as a center of disturbance from which a system of new waves tend to go out. These individual wave-systems ordinarily destroy each other except so far as the onward progression of the wave as a whole is concerned. This is further discussed and illustrated in its application to light-waves (Art. **292** and Figs. 495, 496).

In general, therefore, a given wave is to be considered as the resultant of all these minor wave-systems. If, however, a wave encounters an obstacle in its path, as a narrow opening (*i.e.*, one narrow in comparison with the length of the wave) or a sharp edge, then the fact just mentioned explains how the waves seem to bend about the obstacles, since new waves start from them as centers. This principle has an important application in the case of light-waves, explaining the phenomena of diffraction (Art. **308**).

289. Still another case of wave-motion may be mentioned, since it is particularly helpful in giving a correct apprehension of light-phenomena. If a long rope, attached at one end, be grasped at the other, a quick motion of the hand, up or down, will give rise to a half wave-form—in one case a crest, in the other a trough—which will travel quickly to the other hand and be reflected back with a reversal in its position; that is, if it went forward as a hill-like wave, it will return as a trough. If, just as the wave has reached the end, a second like one be started, the two will meet and pass in the middle, but here for a brief interval the rope is sensibly at rest, since it feels two equal and opposite impulses. This will be seen later to be a case of the simple interference of two like waves opposed in phase.

Again, a double motion of the hand, up and down, will produce a complete wave, with crest and trough, as the result, and this again is reflected back as in the simpler case. Still again, if a series of like motions are continued rhythmically and so timed that each wave is an even part of the whole rope, the two systems of equal and opposite waves passing in the two directions will interfere and a system of so-called stationary waves will

---

* Strictly speaking, the path of each particle approximates closely to a circle.

be the result, the rope seeming to vibrate in segments to and fro about the position of equilibrium.

Finally, if the end of the rope be made to describe a small circle at a rapid, uniform, rhythmical rate, a system of stationary waves will again result, but now the vibrations of the string will be sensibly in circles about the central line. This last case will be seen to roughly indicate the kind of transverse vibrations by which the waves of circularly polarized light are propagated, while the former case represents the vibrations of waves of what is called plane-polarized light.

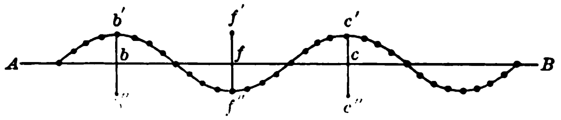
All these cases of waves obtained with a rope deserve to be carefully considered and studied by experiment, for the sake of the assistance they give to an understanding of the complex phenomena of light-waves.

290. Wave-length, Amplitude, etc.—In the cases mentioned, as in all kinds of simple wave-motion, the *length* of a wave is the distance from any one particle of the medium to the next which is moving in the same direction with the same velocity, or, technically expressed, which is in the same *phase*. The *amplitude* of the wave is the excursion to or fro from its position of equilibrium made by each particle in succession. Further, the wave-system travels onward the distance of one wave-length in the time that a given particle makes a complete excursion to and fro.

291. Light-waves.—The propagation of ether-waves involves the same fundamental principles as the familiar forms of wave-motion just considered. Here the motion of the medium is *transverse* to the direction of propagation, and this motion may be regarded as communicated from one set of particles to the next and so on, the ether-waves traveling as concentric spherical waves (in an isotropic medium) outward in all directions from the luminous point.

The nature of the vibrations will be better understood from Fig. 494. If AB represents the direction of propagation of the light, each particle of ether must vibrate at right angles to this as a line of equilibrium. The vibration of the first particle induces a similar movement in the adjacent particle; this is communicated to the next, and so on. The particles vibrate successively from the line AB to a distance corresponding to bb', the *amplitude* of the vibration, then return to b and pass on to b'', and so on. Thus at a given instant there are particles occupying all positions, from that of the extreme distance b', or c', from the line of equilibrium to that on this line. In this way the wave moves forward, while the motion of the particles is only transverse. The distance between any particle and the next which is in a like position—*i.e.*, of like *phase*, as b' and c'—is the *wave-length*; and the time required for this completed movement is the *time* of vibration, or *vibration-period*. The intensity of the light varies with the amplitude of the vibration, and the color, as explained in a later article, depends upon the length of the waves; the length of the violet waves is about one-half the length of the red waves.

494.

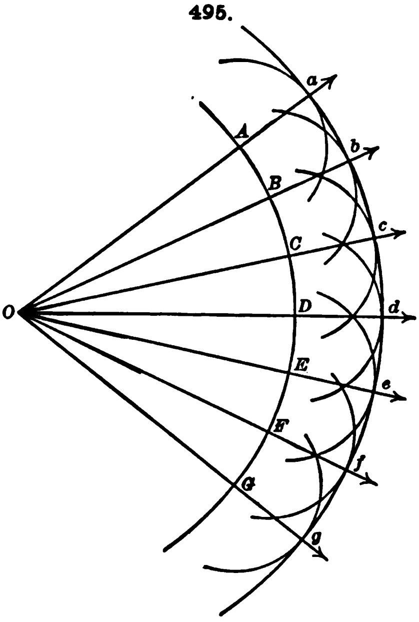


In *ordinary light* the transverse vibrations are to be thought of as taking place in all planes about the line of propagation. In the above figure, vibrations in one plane only are represented; light which is thus one-sided or has only one direction of transverse vibration is said to be *plane-polarized.*

Light-waves have a very minute length, only 0·000023 of an inch for the yellow sodium flame, and they travel with enormous velocity, 186,000 miles per second in a vacuum; thus light passes from the sun to the earth in about eight minutes. The vibration-period, or time of one oscillation, is consequently extremely brief; it is given by dividing the distance traveled by light in one second by the number of waves included.

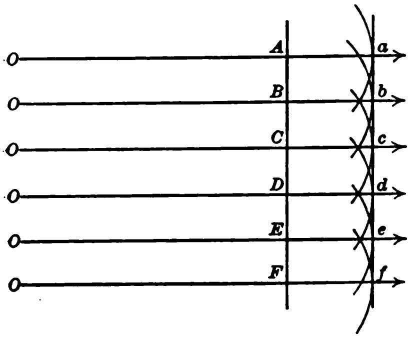
292. Wave-front.—In an isotropic medium, as air, water, or glass—that is, one in which light is propagated in all directions about the luminous point with the same velocity—the waves are spherical in form. The *wave-front* is the continuous surface, in this case spherical, which includes all particles which commence their vibration at the same moment of time. Obviously the curvature of the wave-front diminishes as the distance of the source of light increases, and when the light comes from an indefinitely great distance (as the sun) the wave-front becomes sensibly a plane surface. Such waves are usually called *plane waves.* These cases are illustrated by Figs. 495 and 496. In Fig. 495 the luminous point is supposed to be at *O*, and the medium being isotropic, it is obvious that the wave-front, as *ABC* ... *G*, is spherical. It is also made clear by this figure how, as briefly stated in Art. **288**, the resultant of all the individual impulses which go out from the successive points, as *a, b, c,* etc., as centers, form a new wave-front, *abc*...*g*, concentric with *ABC*... *G*. In Fig. 496 the luminous body is supposed to be at a great distance, so that the wave-front *AB*... *F* is a plane surface. Here also the individual impulses from *A, B,* etc., unite to form the wave-front *ab*... *f* parallel to *AB* ... *F*.

495.



293. Light-ray.—The study of light-phenomena is, in certain cases, facilitated by the conception of a *light-ray*, a line drawn from the luminous point to the wave-front, and whose direction is taken so as to represent that of the wave itself. In Fig. 495 *OA, OB,* etc., are diverging light-rays, and in Fig. 496 *OA, OB,* etc., are parallel light-rays. In both these cases, where the medium is assumed to be isotropic, the light-ray is normal to the wave-front. This is equivalent to saying that the light-wave moves onward in a direction normal to the wave-front.

496.



It must be understood that the "light-ray" has no real existence and is to be taken only as a convenient method of representing the direction of motion of the light-waves under varying conditions. Thus when by appropriate means (*e.g.*, the use of lenses) the curvature of the wave-front is altered—for example, if from being a plane surface it is made sharply convex—then the light-rays, at first parallel, are said to be made to diverge. Again, if the convex wave-front is made plane, the diverging light-rays are then said to be made parallel.

294. Wave-length. Color. White Light.—Notwithstanding the very small length of the waves of light, they can be measured with great precision. The visual part of the waves going out from a brilliantly incandescent body, as the glowing carbons of an electric arc-light, may be shown to consist of waves of widely varying lengths. They include red waves whose length is about $\frac{1}{39000}$ of an inch and waves whose length constantly diminishes without break, through the orange, yellow, green, and blue to the violet, whose minimum length is about half of that of the red. The length of each group of these waves determines the sensation of *color* which the eye perceives. This color is strictly *monochromatic* only when it corresponds to one definite wave-length; this is nearly true of the bright-yellow sodium line, though strictly speaking this consists of two sets of waves of slightly different lengths.

The effect of "*white light*" is obtained if all the waves from the red to the violet come together to the eye simultaneously; for this reason a piece of platinum at a temperature of 1500° C. appears "white hot."

The radiation from the sources named, either the sun, the electric carbons, or the glowing platinum, includes also longer waves which do not affect the eye, but which, like the light-waves, produce the effect of sensible heat when received upon an absorbing surface, as one of lampblack. There are also, particularly in the radiation from the sun, waves shorter than the violet which also do not affect the eye. The former are called *infra-red,* the latter *ultra-violet* waves.

295. Complementary Colors.—The sensation of white light mentioned above is also obtained when to a given color—that is, light-waves of given wave-length—is combined a certain other so-called *complementary* color. Thus certain shades of pink and green combined, as by the rapid rotation of a card on which the colors form segments, produce the effect of white. Blue and yellow of certain shades are also complementary. For every shade of color in the spectrum there is another one complementary to it in the sense here defined. The most perfect illustration of complementary colors is given by the examination of sections of crystals in polarized light, as later explained.

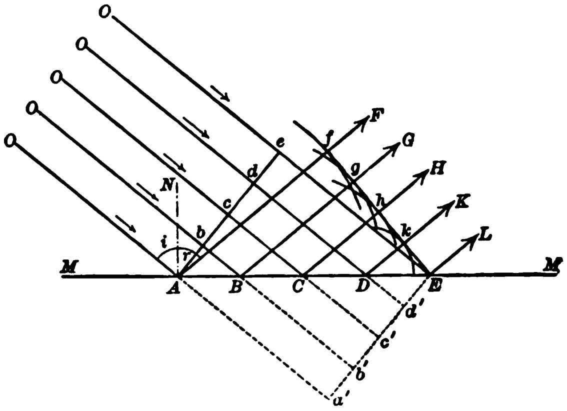
296. Reflection.—When light-waves come to the boundary which separates one medium from another, as a surface of water, or glass in air, they are, in general, in part *reflected* or returned back into the first medium.

The reflection of light-waves is illustrated by Figs. 497 and 498. In Fig. 497, *MM* is the reflecting surface—here a plane surface—and the light-waves have a plane wave-front (*Abcde*); in other words, the light-rays (*OA*, *Ob*, etc.) are parallel. It is obvious that the wave-front meets the surface first at *A* and successively from point to point to *E*. Each of these points is to be regarded as the center of a new wave-system which unimpeded would be propagated onward in a given time distances equal to the lines *Aa′ Bb′*, etc Hence the common tangent *fghkE* to the circular arcs drawn with these radii from *A*, *B*, etc., represents the direction of the new or reflected wave-front. But geometrically the angle *eAE* is equal to *fEA*, or the *incident and reflected wave-fronts make equal angles with the reflecting surface.* If *NA* is a normal at *A*, the angle *OAN*—called the *angle of incidence*—is equal to *NAF,* the *angle of reflection.* Hence the familiar law:

The angle of incidence is equal to the angle of reflection.

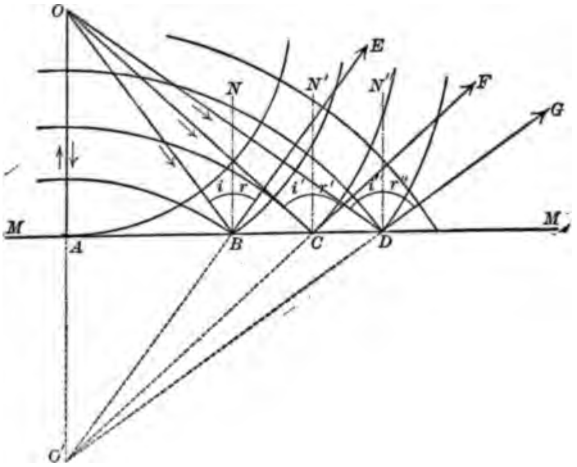
Furthermore, the "incident and reflected rays" both lie in the same plane with the normal to the reflecting surface.

497.



In Fig. 498, where the luminous point is at *O*, the waves going out from it will meet the plane mirror *MM* first at the point *A* and successively at points, as *B*, *C*, *D*, etc., farther away to the right (and left) of *A*. Here also it is easy to show that all the new impulses, which have their centers at *A*, *B*, *C*, etc., must together give rise to a series of reflected waves whose center is at *O'*, at a distance equally distant from *MM* measured on a normal to the surface ($OA = OA'$).

498.



Now the lines *OA*, *OB*, etc., which are perpendicular to the wave-front, represent certain incident light-rays, and the eye placed in the direction *BE*, *CF*, etc., will see the luminous point as if at *O'*. It follows from the construction of the figure and can be proved by experiment that if *BN*, *CN*, etc., are normals to the mirror the angles of incidence, *OBN*, *OCN'*, etc., are equal to the angles of reflection, *NBE*, *N'BF*, etc., respectively. Hence the above law applies to this case also.

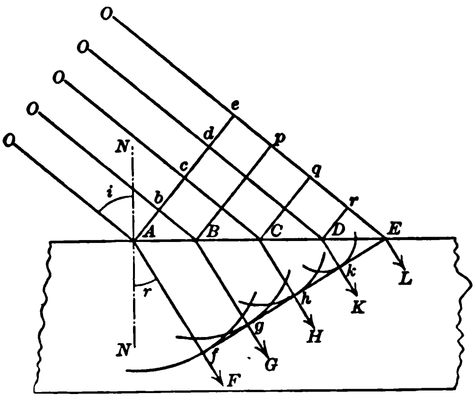
If the reflecting surface is not plane, but, for example, a concave surface, as that of a spherical or parabolic mirror, there is a change in the curvature of the wave-front after reflection, but the same law still holds true.

The proportion of the reflected to the incident light increases with the smoothness of the surface and also as the angle of incidence diminishes. The intensity of the reflected light is a maximum for a given surface in the case of perpendicular incidence (*OA*, Fig. 498).

If the surface is not perfectly polished, *diffuse reflection* will take place, and there will be no distinct reflected ray. It is the diffusely reflected light which makes the reflected surface visible; if the surface of a mirror were *absolutely smooth* the eye would see the reflected body in it only, not the surface itself. Optically expressed, the surface is to be considered smooth if the distance between the scratches upon it is considerably less (say one-fourth) than the wave-length of light.

297. Refraction.—When a system of light-waves of the same wave-length passes from one medium into another there is, in general, an increase or decrease in the velocity of the light, and this results in the phenomenon of *refraction*—that is, a change of direction at the bounding surface. The principles applicable here can be most easily shown in the case of light-waves with a plane wave-front, as shown in Fig. 499—that is, where the light-rays *OA*, *OB*, etc., are parallel. Suppose, for example, that a light-wave, part of whose wave-front is *Abcde*, passes from air obliquely into glass, in which its velocity is about two-thirds as great, and suppose the surface of the glass to be plane. The points *A*, *B*, etc., will be successively centers of disturbance which will be propagated in a given time, not to distances equal to *eE* (from *A* in the line *OA*), to *pE*, etc., but only two-thirds of these distances. Circles drawn from the points *A*, *B*, *C*, etc., with radii equal to these diminished values (two-thirds of *eE*, *pE*, etc.), will have a common tangent in the plane *fghkE*, and this will be then the new wave-front in the second medium. Here it is seen that there is a change of direction in the wave-front, or otherwise stated, in the light-ray, the magnitude of which depends on the ratio between the light-velocities in the two media, and, as discussed later, also upon the wave-length of the light. The light-ray is here said to be broken or *refracted*, and for a medium like glass, optically denser than air (*i.e.*, with a lower value of the light-velocity), the refraction is toward the perpendicular. In the opposite case—in an optically rarer medium—the refraction is away from the perpendicular, the angle of refraction is larger than that of incidence (Art. 303).

499.



298. Refractive Index.—It is obvious from the figure that whatever the direction of the wave-front—that is, of the light-rays—relatively to the given surface, the *ratio* of *eE* to *Af*, which determines the direction of the new wave-front (*i.e.*, the direction of a refracted ray, AF) is constant. This ratio is equal to $\frac{V}{v}$ where V is the value of the light-velocity for the first medium (here air) and v for the second (as glass). If this constant ratio be represented by n, we may write:

$$n = \frac{V}{v} = \frac{eE}{Af} = \frac{AE.\ \text{Sin}\ eAE}{AE.\ \text{Sin}\ AEf} = \frac{\sin eAE}{\sin AEf} = \frac{\sin OAN}{\sin FAN}.$$

Here i (OAN) is the *angle of incidence* and r (FAN) the *angle of refraction;* thus, in its last form,

$$n = \frac{\sin i}{\sin r},$$

we have the familiar relation usually expressed as follows:

The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction.

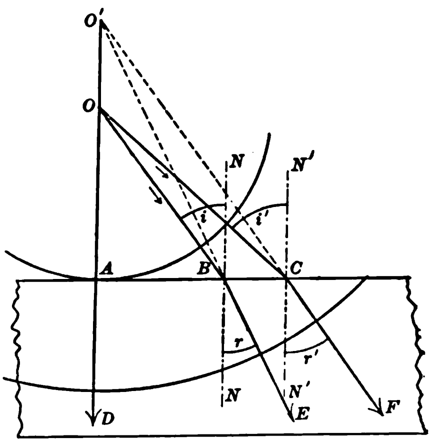
It is also true that the incident and refracted rays lie in a common plane with the normal to the surface.

The above relation holds true for any wave-system of given wave-length in passing from one medium into another, whatever the wave-front or shape of the bounding surface. In Fig. 500 * the luminous point is at O, and it can be readily shown that the new wave-front propagated in the second medium (of greater optical density) has a flattened curvature and corresponding to this a center at O' $\left(\text{where } \frac{O'A}{OA} = \frac{V}{v}\right)$. Here the incident rays OB, OC, are refracted at B and C, the corresponding refracted rays being BE and BF. For this case also the relation holds good,

$$n = \frac{\sin i}{\sin r} = \frac{\sin i'}{\sin r'}, \text{ etc.}$$

This constant ratio for light of a given wave-length passing from one medium to another, expressed here by n, is called the *index of refraction* or *refractive index.* In the examples given for air and crown glass, $\frac{\sin i}{\sin r} = 1{\cdot}608$, and this number consequently gives the value of the refractive index, or n, for this kind of glass.

500.



The relation between wave-length and refractive index is spoken of in Art. **305.**

If the bounding surface is not plane but curved, as in lenses, there is a change in the curvature of the wave-front in the second medium, but the simple law, $n = \frac{\sin i}{\sin r}$, holds true here also, so long as the medium is isotropic.

---

* See S. P. Thompson (Light Visible and Invisible, 1897), who develops the formulas for lenses, etc., on the basis of light-waves instead of light-rays.

299. Relation of Refractive Index to Light-velocity.—The discussion of the preceding article shows that if n is the refractive index of a given substance for waves of a certain length, referred to air, V the velocity in air and v the velocity in the given medium, then

$$n = \frac{V}{v}.$$

For two media whose indices are n_1 and n_2 respectively, it consequently follows that

$$\frac{n_1}{n_2} = \frac{v_2}{v_1}.$$

Therefore, *The indices of refraction of two given media for a certain wave-length are inversely proportional to their relative light-velocities.*

Since light-waves are propagated by a transverse motion in the ether which pervades the given body, and is as it were weighted down by its molecules, it is obvious that the velocity of the light-wave itself is measured by the rate of this transverse motion in the ether; hence for waves of the *same length* traveling through media of different refractive power, this latter velocity of transverse vibration is inversely proportional to the refractive indices.

300. Principal Refractive Indices.—The refractive index has, as stated, a constant value for every substance referred, as is usual, to air (or it may be to a vacuum). In regard to solid media, it is evident from Art. **298** and will be further explained later that those which are *isotropic*, viz., amorphous substances and crystals of the isometric system, can have but a single value of this index. Crystals of the tetragonal and hexagonal (and rhombohedral) systems have, as later explained, *two* principal refractive indices, ϵ and ω, corresponding to the velocities of light-propagation in certain definite directions in them. Further, all orthorhombic, monoclinic, and triclinic crystals have similarly *three* principal indices, α, β, γ. In the latter cases of so-called anisotropic media, the mean refractive index is taken, namely, as the arithmetical mean $\frac{\epsilon + 2\omega}{3}$ and $\frac{\alpha + \beta + \gamma}{3}$.

301. Examples of Refractive Indices.—The following table includes the values of n for a variety of substances, for sodium light. For minerals other than those of the isometric system the average value (as defined in the preceding article) is given here.

Ice	1·310	Boracite	1·667
Water	1·335	Flint Glass	1·702
Fluorite	1·434	Garnet (Pyrope)	1·814
Alum	1·456	Zircon	1·952
Rock-salt	1·544	Cerussite	1·986
Quartz	1·547	Sphalerite	2·369
Calcite	1·601	Diamond	2·419
Crown glass	1·608	Rutile	2·712
Aragonite	1·633	Pyrargyrite	3·016
Barite	1·640		

The refractive index for air referred to the ether of a vacuum is 1·000292 for a wave-length equal to that of yellow sodium light ($\lambda = 0{\cdot}0000589$ cm.).

302. Specific Refractive Power.—The relation between the refractive index and the chemical composition of a given substance is expressed by what has been called the Gladstone law,* namely,

$$\frac{n-1}{d} = \text{constant}.$$

Here n is refractive index (for anisotropic substances, the mean index), and d is the density. The value of the constant is called the *specific refractive power*. The product of the specific refractive power into the molecular weight gives the *refractive equivalent*. Thus for quartz, $n = 1·5$, $d = 2·66$, therefore the value of the specific refractive power is 0·2, and the refractive equivalent is equal to this number multiplied into the molecular weight (60) or 12·6(= 0·2 × 60). Similarly the value obtained† for CaO is 13·3, and for MgO 17·1.

In the case of a complex molecule, it is assumed that the sum of the refractive equivalents of the parts of the molecule divided by the sum of the corresponding molecular weights is equal to the specific refractive power of the given compound. Thus for grossular garnet whose formula may be written $3CaO.Al_2O_3.3SiO_2$, the above relations give

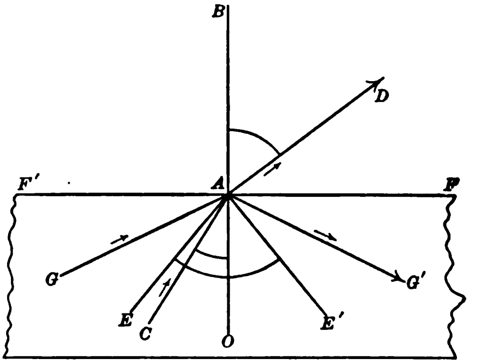
$$\frac{3 \times 13·3 + 19·7 + 3 \times 12·6}{3 \times 56 + 103 + 3 \times 60} = 0·216.$$

Further, $\frac{n-1}{d} = \frac{n-1}{3·5} = 0·216$, and $n = 1·756$; experiment gives $n = 1·747$.

303. Total Reflection. Critical Angle.—In regard to the principle stated in Art. 298 and expressed by the equation $n = \frac{\sin i}{\sin r}$, two points are to be noted. First, if the angle $i = 0°$, then $\sin i = 0$, and obviously also $r = 0$; in other words, when the ray of light (as OA, Fig. 500) coincides with the perpendicular, no change of direction takes place, the ray proceeds onward (AD) into the second medium without deviation, but with a change of velocity.

Again, if the angle $i = 90°$, then $\sin i = 1$, and the equation above becomes $n = \frac{1}{\sin r}$ or $\sin r = \frac{1}{n}$. As n has a fixed value for every substance, it is obvious that there will also be a corresponding value of the angle r for the case mentioned. From the above table it is seen that for water, $\sin r = \frac{1}{1·335}$ and $r = 48°$ $31'$; for crown glass, $\sin r = \frac{1}{1·608}$ and $r = 38°$ $27'$; for diamond, $\sin r = \frac{1}{2·42}$ and $r = 24°$ $25'$.

501.



In Fig. 501 the ray CA in the glass is refracted on passing into the air in the direction AD, but if the angle $EAO = 38°$ $27'$, the ray EA will graze the surface or take the direction AF. Any ray, GA, for which the angle GAO is greater than $38°$ $27'$ will not emerge at all, but suffer *total reflection*, being returned in the direction AG'. The surface of glass illuminated from beneath in the direction last named has a brilliant, almost metallic luster. This is the appearance also, under like conditions, of the surface of a transparent solid—for example, of a glass prism or a cut gem. The value of r thus found is called the *critical angle;* the smaller this angle the greater the apparent *brilliancy* of the given substance.

---

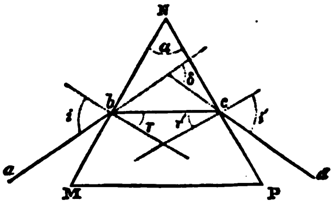
* See Mallard, Tr. Crist., **2**, 476 *et seq.* 1884; Rosenbusch, Mikr. Phys., **1**, 157 1892.

† A table of these values is given by Mallard and reproduced by Rosenbusch.

The relative refractive power of a given substance compared with that of the enclosing medium (*e.g.*, Canada balsam with $n_y = 1{\cdot}539$) determines on the principle of total reflection whether the surface appears rough with dark cracks ("high relief") as in garnet and zircon, or smooth and even ("low relief") as in quartz.

304. Determination of the Refractive Index.—By means of a prism, as *MNP* in Fig. 502, it is possible to determine the value of n, or refractive index of a given substance. The angle of the prism *MNP*, a, is, in each case, measured in the same manner as the angle between two faces of a crystal, and then the *minimum* amount of deviation (δ) of a *monochromatic* ray of light, *e.g.*, yellow sodium light, passing from a slit through the prism is also determined. The amount of deviation of a ray in passing through the prism varies with its position; but when the prism is so placed that the ray makes equal angles with the sides of the prism, that is, with the normals ($i = i'$, Fig. 502), when entering and emerging, this deviation has a *fixed minimum* value.

502.



If δ = the minimum deviation of the ray, and a = the angle of the prism, then

$$n = \frac{\sin \frac{1}{2}(a + \delta)}{\sin \frac{1}{2}a}.$$

The application of this method is given in a later article. Several other methods are also explained—for example, one depending upon total reflection.

305. Dispersion.—Thus far the change in direction which light suffers in reflection and refraction has alone been considered. It is further true that the amount of refraction differs for the waves of different length, that is, the different colors of which ordinary white light is composed, being greater for blue than for red. In consequence of this fact, if ordinary light be passed through a prism, as in Fig. 502, it will not only be refracted, but it will also suffer *dispersion* or be separated into its component colors, thus forming the *prismatic spectrum.*

This variation for the different colors depends directly upon their wave-lengths; the red waves are longer, their transverse vibrations are slower, and it may be shown to follow from this that they suffer less change of velocity on entering the new medium than the violet waves, which are shorter and whose velocity of transverse vibration is greater. Hence the refractive index for a given substance is greater for blue than for red light. The following are values of the refractive indices for diamond determined by Schrauf:

2·40845 red (lithium flame).
2·41723 yellow (sodium flame).
2·42549 green (thallium flame).

306. Spectroscope.—The instrument most simply used for the analysis of the light by dispersion is familiar to all as the *spectroscope.** In it the light from the given source, received through a narrow slit in the end of one tube, is made to fall as a plane-wave (that is, as a "pencil of parallel rays") upon one surface of a prism at the center, and the spectrum produced is viewed through a suitable telescope at the end of a second tube.

---

* A. de Gramont has shown that the direct spectroscopic examination of many mineral

If the light from an incandescent solid—which is "white hot" (Art. **294**)—is viewed through the spectroscope, the complete band of colors of the spectrum is seen from the red through the orange, yellow, green, blue, to the violet. If, however, the light from an incandescent vapor is examined, it is found to give a spectrum consisting of bright lines (or bands) only, and these in a definite position characteristic of it—as the yellow line (double line) of sodium vapor; the more complex series of lines and bands, red, yellow, and green, characteristic of barium; the multitude of bright lines due to iron vapor (in the intensely hot electric arc), and so on.

307. Absorption.—Of the light incident upon the surface of a new medium, not only is part reflected (Art. **296**) and part transmitted and refracted (Art. **297**), but, in general, part is also *absorbed* at the surface and part also during the transmission. Physically expressed, absorption in this case means the transformation of the ether-waves into sensible heat, that is, into the motion of the molecules of the body itself.

The color of a body gives an evidence of this absorption. Thus a sheet of red glass appears red to the eye by *transmitted light*, because in the transmission of the light-waves through it, it absorbs all except those which together produce the effect of red. For the same reason a piece of jasper appears red by *reflected* light, because it absorbs part of the light-waves at the surface, or, in other words, it reflects only those which together give the effect of this particular shade of red.

Absorption in general is *selective* absorption; that is, a given body absorbs particular parts of the total radiation, or, more definitely, waves of a definite wave-length only. Thus, if transparent pieces of glass of different colors are held in succession in the path of the white light which is passing into the spectroscope, the spectrum viewed will be that due to the selective absorption of the substance in question. A layer of blood absorbs certain parts of the light so that its spectrum consists of a series of absorption bands. Certain rare substances, as the salts of didymium, etc., have the property of selective absorption in a high degree. In consequence of this, a section of a mineral containing them often gives a characteristic absorption spectrum.

The dark lines of the solar spectrum, of which the so-called Fraunhofer lines are the most prominent, are due to the selective absorption exerted by the solar atmosphere upon the waves emitted by the much hotter incandescent mass of the sun.

308. Diffraction.—When monochromatic light is made to pass through a narrow slit, or by the sharp edge of an opaque body, it suffers *diffraction*, and there arise, as may be observed upon an appropriately placed screen, a series of dark and light bands, growing fainter on the outer limits. Their presence is explained (see Arts. **312**, **313**) as due to the interference, or mutual reaction, of the adjoining systems of waves of light, that is, the initial light-waves, and further, those which have their origin at the edge or sides of the slit in question. It is essential that the opening in the slit should be small as compared with the wave-length of the light. If ordinary light is employed,

---

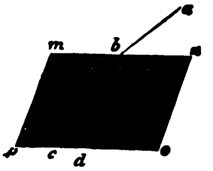
species (galena, pyrite) serves as a method of qualitative analysis and gives interesting results. Bull. Soc. Min., **18**, 171–373, 1895.

the phenomena are the same, and for the same causes, except that the bands are successive colored spectra.

Diffraction spectra, explained on the principles alluded to, are obtained from diffraction gratings. These gratings consist of a series of extremely fine parallel lines (say 15,000 or 20,000 to an inch) ruled with great regularity upon glass, or upon a polished surface of speculum metal. The glass grating is used with transmitted, and the speculum grating with reflected, light; the Rowland grating of the latter kind has a concave surface. Each grating gives a number of spectra, of the first, second, third order, etc. These spectra have the advantage, as compared with those given by prisms, that the dispersion of the different colors is strictly proportional to the wave-length.

309. Double Refraction.—In the discussion of Art. **297**, applying to isotropic media, it was shown that light-waves passing from one medium into another, which is also isotropic, suffer simply a change in wave-front in consequence of their change in velocity. In anisotropic media, however, which include all crystals but those of the isometric system, there are, in general, two wave-systems propagated with different velocities and only in certain limited cases is it true that the light-ray is normal to the wave-front. This subject cannot be adequately explained until the optical properties of these media are fully discussed, but it must be alluded to here since it serves to explain the familiar fact that, while with glass, for example, there is only one refracted ray, many other substances give two refracted rays, or, in other words, show *double refraction*.

503.



The most familiar example of this property is furnished by the mineral calcite, also called on account of this property "doubly-refracting spar." If *mnop* (Fig. 503) be a cleavage piece of calcite, and a ray of light meets it at *b*, it will, in passing through, be divided into two rays, *bc*, *bd*. For this reason, a dark spot or a line seen through a piece of calcite ordinarily appears double. As implied above and also in Art. **300** the same property is enjoyed by all crystallized minerals, except those of the isometric system. The wide separation of the two refracted rays by calcite, which makes the phenomenon so striking, is a consequence of the large difference in the values of its indices of refraction, in other words, as technically expressed, it is due to the *strength* of its double refraction, or its *birefringence.*

310. When the incident light is perpendicular to the surface of the doubly-refracting substance, there is, in the more commonly occurring cases, no change of direction in the transmission; but even then it is usually still true that the incident ray is divided into two rays, which, though they may travel in the same path, yet have different velocities, so that one falls behind the other. Further, as later explained, each is in general plane-polarized. For each of these rays, it is true that for waves of the *same length* the rate of transverse vibration, and hence the velocity of the ray itself, is inversely proportional to the respective refractive index.

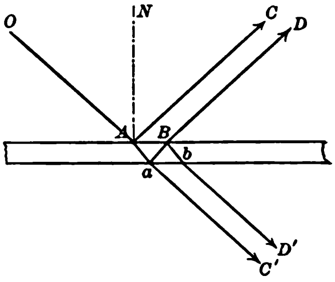
311. Interference of Waves in General.—The subject of the interference of light-waves, alluded to in Art. **308**, requires detailed discussion. It is one of great importance, since it serves to explain many common and beautiful phenomena in the optical study of crystals, for example, the axial interference figures shown on the plate forming the frontispiece.

Referring again to the water-waves spoken of in Art. **287**, it is easily understood that when two wave-systems, going out, for example, from two centers of disturbance near one another, come together, if at a given point they meet in the same phase (as crest to crest), the result is to give the particle in question double amplitude of motion. On the other hand, if at any point the two wave-systems come together in opposite phases, that is, half a wave-length apart, the crest of one corresponding to the trough of the other, they interfere and the amplitude of motion is zero. Under certain conditions, therefore, two sets of waves may unite to form waves of double amplitude; on the other hand, they may mutually interfere and destroy each other. Obviously an indefinite number of intermediate cases lie between these extremes. What is true of the waves mentioned is true also of sound-waves and of wave-motion in general. A very simple case of interference was spoken of in connection with the discussion of the waves carried by a long rope (Art. 289).

312. Interference of Light-waves.—Interference phenomena can be most satisfactorily studied in the case of light-waves. The extreme cases are as follows: If two waves of like length and intensity, and propagated in the same direction, meet in the same phase, they unite to form a wave of double intensity (double amplitude). If, however, the waves differ in phase by half a wave-length, or an odd multiple of this, they *interfere* and extinguish each other. For other relations of phase they are also said to interfere, forming a new resultant wave, differing in amplitude from each of the component waves. In these cases monochromatic light-waves were assumed (that is, those of like length). If ordinary white light is used, the waves in the case of interference will overlap, and their interference will be indicated by the appearance of the colors of the spectrum.

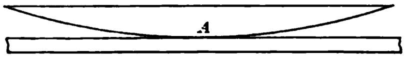
313. Illustrations of Interference.—A simple illustration is afforded by the bright colors of very thin films or plates, as a film of oil on water, a soap-bubble, and like cases. To understand these, it is only necessary to remember that the incident light-waves are reflected in part from the upper and in part from the lower surface of the film or plate. Hence if the thickness is very small, these two reflected wave-systems. when they come together (represented in Fig. 504 by the two rays *AC*, *BD*) will differ from one another in phase, and interfering give rise (in ordinary light) to the colored phenomena spoken of. It is to be noted that the phenomena of interference by reflection are somewhat complicated by the fact that there is a reversal of phase (that is, a loss of half a wave-length) at the surface which separates the medium of greater optical density from the rarer one. Hence the actual relation in phase of the two reflected rays, as *AC*, *BD* (supposing them of the same wave-length) is that determined by the retardation due to the greater length of path traversed by *Bd*, together with the loss of a half wave-length due to the reversal of phase spoken of. As shown in the figure, there are also two transmitted waves which also interfere in like manner.

504.



A plano-convex lens of long curvature, resting on a plane glass surface (Fig. 505), and hence separated from it, except at the center, by a film of air of varying thickness, gives by reflected monochromatic light a dark center and about this a series of light and dark rings, called *Newton's rings*. The dark center is due to the interference of the incident and reflected waves, the latter half a wave-length behind the former. The light rings correspond to the distances where the two sets of reflected waves meet in the *same phase*, that is (noting the explanation above) where the retardation of those having the longer path is a half wave-length or an odd multiple of this ($\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc.). Similarly the dark rings fall between these and correspond to the points where the two waves meet in opposite phase, the retardation being a wave-length or an even multiple of this. The rings are closer together with blue than with red because of their smaller wave-length. In each of the cases described the ring is properly the intersection on the plane surface of the cone of rays of like retardation.

505.



In ordinary white light there can be no dark rings because of the difference of length of the component waves; on the contrary, the overlapping of these waves produces a series of *colored rings*, each showing the successive colors of the spectrum. The series of colors are distinguished as of the first, second, third, etc., order; for a given color, as red, may be repeated a number of times as the waves overlap. After a certain number of waves have overlapped in this way, white light ("of a higher grade") results.

Similarly in the case of the thin plate in white light, a certain thickness and consequent retardation produces a superposition of the waves which yields, for example, a shade of red; a greater thickness (and retardation) a red of the second order, etc. If the plate is not very thin, simple white is reflected from it.

Another most satisfactory illustration of the interference of light-waves is given by means of the diffraction gratings spoken of in Art. **308**, but the subject cannot be further discussed in this place.

Other cases of the composition of two systems of light-waves will be considered after some remarks on polarized light.

314. Polarization and Polarized Light.—Ordinary light is propagated by transverse vibrations of the ether which take place alike in all planes about the line of propagation. A ray of ordinary light is, therefore, alike or symmetrical in all directions about this line; it may be most simply thought of as being propagated by two equal sets of transverse vibrations taken in any two planes at right angles to each other.

Plane-polarized light, on the other hand, as stated briefly in Art. **291**, is propagated by ether-vibrations which take place *in one plane only*. The change by which ordinary light is changed into a polarized light is called *polarization*, and the plane at right angles to the plane of transverse vibration is called the *plane of polarization.**

Polarization may be accomplished (1) by reflection and by single refraction, and (2) by double refraction.

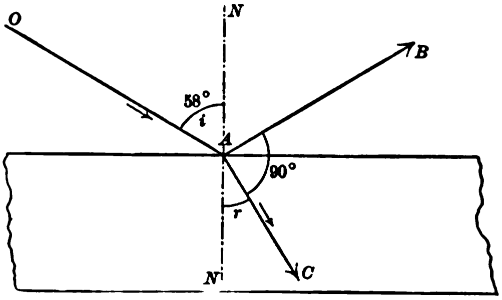
315. Polarization by Reflection and Single Refraction.—In general, light which has suffered reflection from a surface like that of polished glass is more or less completely polarized; that is, the reflected waves are propagated by vibrations to a large extent limited to a single plane, viz., (as assumed) the plane normal to the plane of incidence, which last is hence the plane of polarization. Furthermore, in this case, the light transmitted and refracted by the reflecting medium is also in like manner partially polarized; that is, the vibrations are more or less limited to a single plane, in this case a plane at right angles to the former and hence coinciding with the plane of incidence. For a given angle of incidence, varying for each substance, but such that the reflected and refracted rays (*AB* and *AC*, Fig. 506) make an angle of 90° with each other, this polarization is a maximum. For this case it is hence true, if we represent this angle of polarization by i, that

---

* This is in accordance with the assumption of Fresnel; with MacCullagh the vibration-plane and plane of polarization coincide. All ambiguity is avoided by speaking uniformly of the *vibration-plane* of the light.

$$\tan i = n.$$

506.

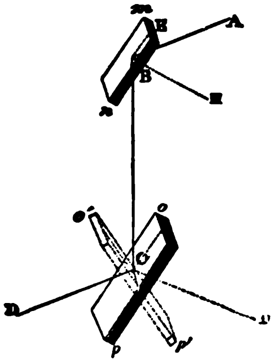


This law, established by Brewster, may be stated as follows:

The angle of polarization is that angle whose tangent is the index of refraction of the reflecting substance. For crown glass this angle is about 58° (see Fig. 506). If light suffers repeated reflections from a series of thin glass plates, the polarization is more complete, though its intensity is weakened. Metallic surfaces polarize the light very slightly.

If the polarized light-waves fall upon a second similar reflecting surface at the same angle, they will be reflected again unchanged, on the condition that the two planes of incidence (and hence the two planes of polarization) of the two mirrors coincide. If, however, these planes are at right angles to each other, the light polarized by the first mirror will be extinguished by the second. As the polarization is in no position absolutely complete, the light is not completely arrested, but only reduced to a minimum in the second position.

507.



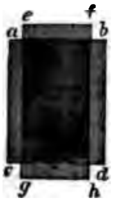
This case is illustrated by Fig. 507. Here the incident ray *AB* is reflected by the first mirror *mn* in the direction *BC* and polarized in a plane normal to the plane of incidence—the angle *ABH* being equal to the angle of polarization. If now the second mirror occupy either of the positions *op* or *o'p'*, the planes of incidence (and of polarization) of both mirrors coincide and the light-ray, *BC*, is, therefore, reflected a second time in the direction of *oD*, or *oD'*. If, however, the second mirror be revolved about a vertical axis the reflected light becomes gradually weaker and is sensibly extinguished when the two planes of incidence are at right angles to each other.

316. Polarization by Double Refraction.—When light in passing through a crystalline medium is doubly refracted (Art. **309**) or divided into two sets of waves, it is always true that both are completely polarized and in planes at right angles to each other. This subject can only be satisfactorily explained after a full discussion of the properties of anisotropic crystalline media, but it may be alluded to here since this principle gives the most satisfactory method of obtaining polarized light. For this end it is necessary that one of the two wave-systems should be extinguished, so that that due to a single set of vibrations only is transmitted. This is accomplished by natural absorption in the case of tourmaline plates and by artificial means in the nicol prisms of calcite.

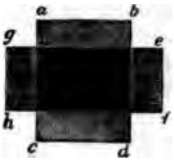
317. Polarized Light by Absorption.—If from a crystal of tourmaline, which is suitably transparent, two sections be obtained, each cut parallel to the vertical axis, it will be found that these, when placed together with the direction of their axes coinciding, allow the light to pass through. If, however, one section is revolved upon the other, less and less of the light is transmitted, until, when their axes are at right angles (90°) to each other, the light is (almost perfectly) extinguished. As the revolution is continued, more and more light is obtained through the sections, and after a revolution of 180°, the axes being again parallel, the appearance is as at first. A further revolution (270°) brings the axes again at right angles to each other, when the light is a second time extinguished, and so on around.

The explanation of this phenomenon, so far as it can be given here, is analogous to that employed for the case of polarization by reflection. Each plate doubly refracts the light; but one of the two sets of waves is absorbed, and only that set whose vibrations are parallel to the vertical axis are transmitted. If now the two plates are placed in the same position, *abdc*, and *efhg* (Fig. 508), the light passes through both in succession. If, however, the one is turned upon the other, only that portion of the light can pass through which vibrates still in the direction *ac*. This portion is determined by the resolution of the existing vibrations in accordance with the principle of the parallelogram of forces. Consequently, when the sections stand at right angles to each other (Fig. 509) the amount of transmitted light is nearly zero, that is, the light is extinguished. Instead of tourmaline, an artificial salt, the sulphate of iodoquinine (herapathite) is sometimes employed, but it has little practical value.

508.

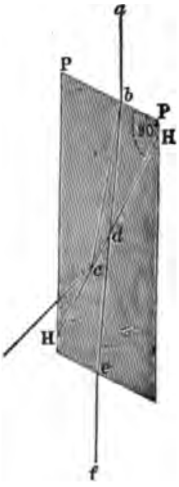


509.

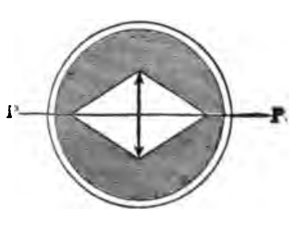


318. Polarized Light by Nicol Prisms.—The most satisfactory method of obtaining polarized light is by means of a prism of transparent calcite (Iceland spar). Fig. 510 shows the principle involved in the prism early constructed by Nicol, which transmits one only of the two refracted rays, that represented by the line *bde* (the extraordinary ray, as later defined). The other ray, *bc*, suffers total reflection at the surface where the two sections are united together by Canada balsam and is then absorbed by the black surface of the sides. Here the vertical faces are natural cleavage-faces; the face *PP* is ground on so as to make an angle of 68° with the obtuse vertical angle; the prism so formed is cut diagonally across (*HH*), and then the parts cemented together. This form of prism, as well as others somewhat different in form but accomplishing the same end with the use of less material, is ordinarily called a Nicol prism, or briefly a *nicol*. The section of the ordinary nicol of Fig. 510 is

510.



511.



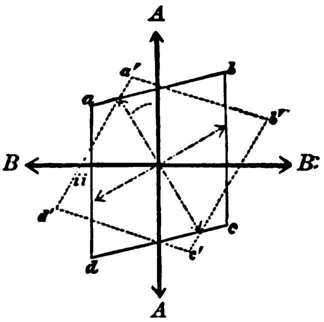
lozenge-shaped (Fig. 511); the plane of polarization, PP, passes through the obtuse angles of the cross-section, and the vibration-plane, here as usual represented by a double-headed arrow, passes through the acute edges. The other prisms alluded to may have a rectangular cross-section. The vibration-plane can be readily determined in any case by examining with it the light reflected from some suitable surface (*e.g.*, of a wood table). Twice in a revolution of the prism through 360° about its axis this light will be weakened; when this is true, the vibration-plane of the prism must be perpendicular to that of the partially polarized reflected light, that is, it must be *vertical*, since the latter is taken as horizontal.

319. Polariscope. Polarizer. Analyzer.—The combination of two nicols, or other polarizing contrivances, for the examination of a substance in polarized light is called, in general, a *polariscope;* the common forms are described later. In any polariscope the prism, or other contrivance, which polarizes the light given from the outside source is called the *polarizer;* the other is the *analyzer.* If the prisms have their vibration-planes at right angles to each other, they are said to be *crossed;* the incident light polarized by the polarizer is then extinguished by the analyzer; briefly, it is said to suffer *extinction.*

320. Interference of Plane-polarized Waves. Interference-colors. — The simplest case of the interference (Art. 312) of polarized light to consider is that where the two light-waves, or, more simple expressed, two rays, are polarized in the *same plane.* They may then interfere to extinguish each other, or they may give rise to beautiful color-effects.

Suppose, for example, that in a polarization-microscope (Art. 328) parallel light passes upwards through the lower nicol, whose vibration-plane is shown in the cross-section of Fig. 512 by the arrow AA; this light is polarized in a single plane. Now let this polarized light pass through a thin cleavage-plate of selenite; it will in general be separated into two rays, each polarized in planes at right angles to the other, having a definite position peculiar to this substance. Thus, in Fig. 512, if *abcd* represents the selenite plate, its vibration-planes have the directions of the dotted arrows. The two rays corresponding to them travel through the section with unequal velocity, and on emerging one is slightly retarded as compared with the other. Now let these light-rays pass through a second nicol, with its vibration-plane at right angles to that of the first nicol, that is, in the direction of the arrow BB. Then each of the two sets of vibrations (represented by the dotted arrows) will have a component in the direction of BB, and these will emerge now polarized in the same plane, and hence capable of interfering, for light-rays can only thus completely interfere when their vibrations are in a common plane. Further, an amount of light corresponding to the other components (in the direction AA) will be extinguished. One of these emergent rays is, as stated, slightly retarded as compared with the other. The amount of this retardation obviously varies with the strength of the double refraction (in this case $\gamma - \alpha$), and also with the thickness of the section taken. The interference-color of the section, supposing ordinary light to be used, depends upon these two conditions, and may be calculated for a given substance. Thus a plate of selenite of a thickness of 0·055 mm. will give a red (of the *first order*), and if thinner,

512.



a yellow or gray. As the thickness increases, the colors (now of the *second order*) pass through successive shades of blue, green, yellow, orange, and if the plate is of sufficient thickness a second red and so on (see, further, Arts. **359** and **382**). A mineral of very strong double refraction, as calcite, shows only the white of the higher order unless extremely thin.

If the section had happened to have the position of *a'b'c'd'* (Fig. 512), its vibration-planes would have coincided with those of the two nicols, and the light, after passing through the first nicol and the section, would have been propagated by vibrations in the direction *AA* only, and hence have been completely extinguished by the second nicol. The plate would then have appeared dark.

The successive interference-colors* of the *first order* pass from an iron-gray through bluish-gray to white, yellow, and red; then follow indigo, blue, green, yellow, orange, and red of the *second order;* then the similar but paler series of colors of the *third order*, and finally the very pale shades of green and red of the *fourth order*. Beyond this the colors are not very distinct; white of a higher order finally results from the interference.

An excellent colored plate showing these colored bands is given by Lévy and Lacroix (Les Minéraux des Roches, 1888). It is so arranged as to give the thickness of the section of a given mineral (all important species present in rocks being included) which will yield any one of the different shades of color mentioned. The use to which such a plate may be put in the practical determination of the birefringence of a given mineral will be referred to later.

321. Complementary Colors in Polarized Light.—If in the examination of the selenite plate, as just described (Art. **320**), one of the nicols had been rotated 90°, or, in other words, if the vibration-planes of the two nicols had been made parallel, then it is obvious that interference would also have taken place between the emerging rays, but the color resulting in each case would have been exactly the *complementary* tint to that obtained at first when the nicols were crossed. The section in the position *a'b'c'd'* between parallel nicols obviously would appear white.

322. In the preceding articles the two interfering light-rays, after emerging from the second nicol, were assumed to be polarized in the same plane; for them the resulting phenomena as indicated are comparatively simple. If, however, two plane-polarized rays propagated in the same direction have their vibration-directions at right angles to each other, and if they differ one-quarter of a wave-length ($\frac{1}{4}\lambda$) in phase (assuming monochromatic light), then it may easily be shown that the composition of these two systems results in a ray of *circularly polarized* light. Briefly expressed, this is a ray which looked at end-on would seem to be propagated by ether-vibrations taking place in circles about the line of transmission. From the side, the onward motion would be like that of a screw, and either right-handed or left-handed.

If, again, two light-rays meet as above described, with a difference of phase differing from $\frac{1}{4}\lambda$ (but not equal to an even multiple of $\frac{1}{4}\lambda$), then the resulting composition gives rise to *elliptically polarized* light, that is, a light-ray propagated by ether-motions taking place in ellipses.

The above results are obtained most simply by passing plane-polarized light through a doubly refracting medium of the proper thickness (*e.g.*, a mica plate) which is placed with its vibration-planes inclined 45° to that of the polarizer. If the thickness is such as to give a difference in phase of $\frac{1}{4}\lambda$ or an odd multiple of this, the light which emerges is circularly polarized. If the phase differs from $\frac{1}{4}\lambda$ (but is not equal to $\frac{\lambda}{2}$ or λ), the emergent light is elliptically polarized.

---

* See further the table given in the following article; also the explanation of the "ultra-blue" on p. 428.

The following table from Klein[*] gives the relation between the retardation from $\frac{1}{8}\lambda$ to 2λ (λ = wave-length) for a section of a doubly refractive substance, the interference-color it yields, and the state of the transmitted light as regards polarization. The section is supposed to be observed in parallel sodium light with crossed nicols; further, the vibration-direction corresponding to the greater refractive index in the section runs from left in front to right behind.

Retardation for Na light.	*Interference-color* Nicols (+), white light.		*Kind of Polarization.*
$\frac{1}{8}\lambda$	Lavender-gray	1ST ORDER	Elliptic, right-handed.
$\frac{1}{4}\lambda$	Grayish-blue	"	Circular, "
$\frac{3}{8}\lambda$	Clearer-gray	"	Elliptic, "
$\frac{1}{2}\lambda$	Pale straw-yellow	"	*Plane-polarized.*
$\frac{5}{8}\lambda$	Bright yellow	"	Elliptic, left-handed.
$\frac{3}{4}\lambda$	Brownish-yellow	"	Circular, "
$\frac{7}{8}\lambda$	Orange	"	Elliptic, "
λ	Red	"	*Plane-polarized.*
$\frac{9}{8}\lambda$	Indigo	2D ORDER	Elliptic, right-handed.
$\frac{5}{4}\lambda$	Azure-blue	"	Circular, "
$\frac{11}{8}\lambda$	Green	"	Elliptic, "
$\frac{3}{2}\lambda$	Brighter green	"	*Plane-polarized.*
$\frac{13}{8}\lambda$	Yellow	"	Elliptic, left-handed.
$\frac{14}{8}\lambda$	Orange	"	Circular, "
$\frac{15}{8}\lambda$	Reddish-orange	"	Elliptic, "
2λ	Dark violet-red	"	*Plane-polarized.*

323. Crystals Giving Circular Polarization.—In the case of certain doubly refracting crystallized media (as quartz), and also of certain solutions (as of sugar), it can be shown that the light is propagated by two sets of ether-vibrations which take place, not in definite transverse planes—as in plane-polarized light—but in circles; that is, each ray is circularly polarized, one being right-handed, the other left-handed. Further, of these rays, one will uniformly gain with reference to the other. The result is, that if a ray of plane-polarized light fall upon such a medium (assuming the simplest case, as of a section of quartz cut normal to the axis), it is found that the two rays circularly polarized within unite on emerging to a plane-polarized ray, but the plane of polarization has suffered an angular change or rotation, which may be either to the right (to one looking in the direction of the ray), when the substance is said to be *right-handed*, or to the left, when it is called *left-handed*.

This phenomenon is theoretically possible with all crystals of a given system belonging to any of the groups of lower symmetry than the normal group which show a plagihedral development of the faces;[†] or, more simply, those in which the corresponding right and left (or + and −) typical forms are enantiomorphous (pp. 50, 82), as noted in the chapter on crystallography. In mineralogy, this subject is most important with the common species quartz, of the rhombohedral-trapezohedral group, and a further discussion of it is postponed to a later page (Art. 366).

---

[*] Ber. Ak. Berlin, 221, 1893.

[†] Of the thirty-two possible groups among crystals, the following eleven may be characterized by circular polarization: Group 4, p. 50; 5, p. 51; 11 and 12, p. 68; 17, p. 78; 22, p. 82; 23 and 24, p. 84; 27, p. 96; 29, p. 108; 32, p. 109.

OPTICAL INSTRUMENTS AND METHODS.

324. Measurement of Refractive Indices. Refractometer.—For the determination of the refractive indices of crystallized minerals various methods are employed. The most accurate results, when suitable material is at hand, may be obtained by the ordinary refractometer. This requires the observation of the angle of minimum deviation (δ) of a light-ray on passing through a prism of the given material, having a known angle (a), and with its edge cut in the proper direction. The measurements of a and δ can be made with an ordinary refractometer or with the horizontal goniometer described in Art. **210**. For the latter instrument, the collimator is made stationary, being fastened to a leg of the tripod support, but the observing telescope with the verniers moves freely. Further, for this object the graduated circle is clamped, and the screw attachments connected with the axis carrying the support, and the vernier circle and observing telescope are loosened. Light from a monochromatic source passes through an appropriate slit and an image of this is thrown by the collimator upon the prism. With a doubly refracting substance two images are yielded and the angle of minimum deviation must be measured for each; the proper direction for the edge of the prism in this case is discussed later. In cases where the highest degree of accuracy is desired sunlight is employed and the angle of deviation measured for the prominent Fraunhofer lines (p. 171). When a and δ are known the formula in Art. **304** is used.

325. Total Reflectometer.—The principle of total reflection (Art. **303**) may also be made use of to determine the refractive index. No prism is required, but only a small fragment having a single polished surface; this may have any direction with an isometric crystal, but in other cases must have a definite orientation, as described later. The arrangements required (as developed by F. Kohlrausch) are, in their simplest form, a wide-mouthed bottle filled with a liquid of high refractive power, as carbon disulphide ($\mu_y = 1{\cdot}6442$ Na) or α-bromnaphthalin ($\mu_y = 1{\cdot}6626$ Na). The top is formed by a fixed graduated circle, and a vertical rod, with a vernier attached, passes through the plate and carries the crystal section on its extremity, immersed in the liquid. The angle through which the crystal surface lying in the axis is turned is thus measured by the vernier on the stationary graduated circle. The front of the bottle is made of a piece of plate glass, and through this passes the horizontal observing telescope, arranged for parallel light. The rest of the surface of the bottle is covered with tissue-paper, through which the diffuse illumination from say a sodium flame has access; the rear of the bottle is suitably darkened. When now the observer looks through the telescope, at the same time turning the axis carrying the crystal section, he will finally see, if the source of illumination is in a proper oblique direction, a sharp line marking the limit of the total reflection. The angle is measured off on the graduated circle, when this line coincides with one of the spider lines of the telescope. Now the crystal is turned in the opposite direction, and the angle again read off. Half the observed angle (2α) is the angle of total reflection; if μ is the refractive index of the carbon disulphide, then the required refractive index, n, is equal to

$$\mu \sin \alpha.$$

Under favorable conditions the results are accurate to four decimal places. This method is limited, obviously, to substances whose refractive index is less than that of the liquid medium with which the bottle is filled.

Different forms of total reflectometers* have been devised by Soret, Pulfrich, Czapski, and others.

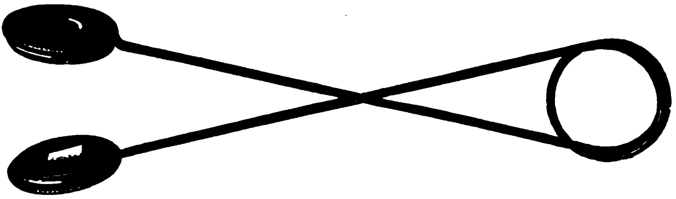
326. The method of obtaining the refractive index of a transparent medium, first described by Duke de Chaulnes (1767), has been shown by Sorby † to allow, under suitable conditions, of determinations of considerable accuracy. This method consists essentially in observing the distance (d) which the focal distance of the objective is changed when a plane-parallel plate of known thickness (t) is introduced perpendicular to the axis of the microscope between the objective and the focal point, here

$$\mu = \frac{t}{t - d}.$$

Sorby made use of a glass micrometer, upon which two systems of lines perpendicular to each other were ruled. A micrometer-screw in the microscope makes it possible to measure the distance through which the tube is raised and lowered down to ·001 mm.; consequently both t and d can be obtained with a high degree of accuracy.‡

327. Tourmaline Tongs.—A very simple form of polariscope for converging light is shown in Fig. 513; it is convenient in use, but of limited application. Here the polarizer and analyzer are two tourmaline plates such as were described in Art. 317. They are mounted in pieces of cork and held in a kind of wire pincers. The object to be examined is placed between them and supported there by the spring in the wire. In use they are held close to the eye, and in this position the crystal section is viewed in *converging* polarized light, with the result of showing (under proper conditions) the axial interference-figures (Arts. 360 and 387).

513.



328. Polariscope. Conoscope. Stauroscope.—The common forms of polariscope § employing nicol prisms are shown in Figs. 514 and 515.‖ Fig. 514 represents the instrument arranged for converging light, which is often called a *conoscope*.

The essential parts are the mirror S, reflecting the light, which after passing through the lens e is polarized by the prism p. It is then rendered strongly converging by the system of lenses nn, before passing through the section under examination placed on a plate at *k*. This plate can be revolved through any angle desired, measured on its circumference. The upper tube

---

* See Groth, Phys. Kryst., 1895, pp. 654–679; also Das Reflectometer, etc., von Dr. C. Pulfrich, Leipzig, 1890.

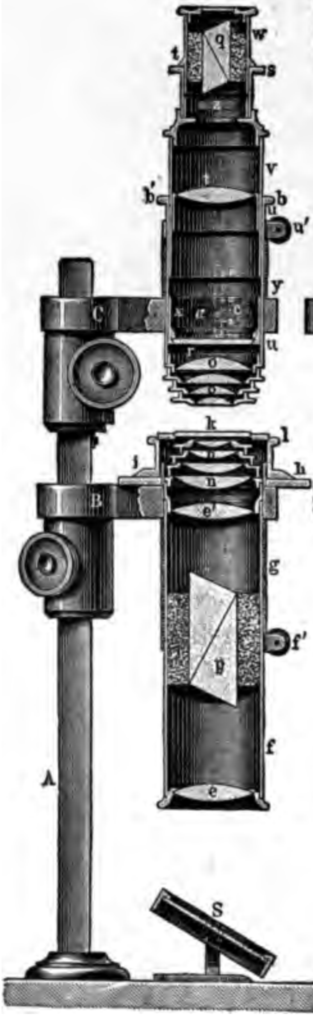
† Min. Mag., 2, 1, 101, 1878.

‡ Cf. Rosenbusch, Micr. Phys. Min., p. 84, 1892, who mentions particularly methods applicable to minerals in thin sections.

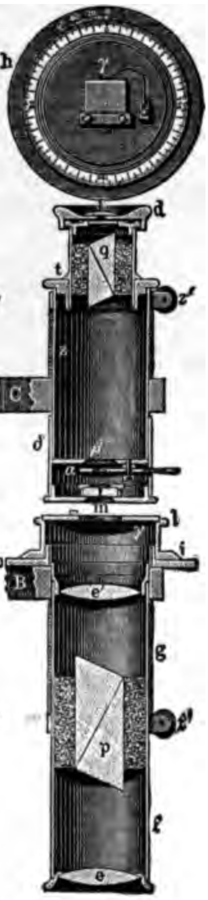
§ See further, Groth, Phys. Kryst. (also Pogg. Ann., 144, 34, 1871).

‖ These figures, also Figs. 516, 517, 544, are taken from the catalogue of R. Fuess, Steglitz, Berlin.

514.



515.



contains the converging system *oo*, the lens *t*, and the analyzing prism *q*. The arrangements for lowering or raising the tubes need no explanation, nor indeed the special devices for setting the vibration-planes of the nicols at right angles to each other.

The accompanying tube (Fig. 515) shows the arrangement for observations in parallel light, the converging lenses having been removed. In this form it is especially used for stauroscopic measurements, as later explained. In some forms of polariscope of the above type the place of the analyzer is taken by a pair of black glass mirrors set at the proper polarizing angle.

329. Polarization-Microscope.—The investigation of the form and optical properties of minerals when in microscopic form has been much facilitated by the use of microscopes* specially adapted for this purpose. First arranged with reference to the special study of minerals as seen in thin sections of rocks, they have now been so elaborated as largely to take the place of the older optical instruments. They not only allow of the determination of the optical properties of minerals with greater facility, but are applicable to many cases where the crystals in hand are far too small for other means.

A highly serviceable microscope, for general use, is that described by Rosenbusch in 1876 and later much improved. A sectional view of one form is shown in Fig. 516, and a later and improved pattern is given in Fig. 517. The essential arrangements of Fig. 516 are as follows: The tube carrying the eyepiece and objective has a fine adjustment-screw at *g*; the coarse adjustment is accomplished by the hand. The screw-head *g* is graduated and turns about a fixed index attached to the tube *p*; by this means the distance through which the tube is raised or lowered can be measured to 0·001 mm. The polarizing prism is placed below the stage at *r*, in a support with a graduated circle, so that the position of its vibration-plane can be fixed. The analyzing prism is contained in a cap, *ss*, which is placed over the eyepiece; this may be revolved at pleasure, its edge being graduated. When both prisms are set at the zero mark, their vibration-planes are crossed (⊥); when either is turned 90°, the planes are parallel (‖). The stage is made to rotate about the vertical axis, but otherwise (in this simple form) is fixed; its edge is graduated, so that the angle through which it is turned can be measured to ½°. Three adjustment-screws, of which one is shown at *n*, *n*, make it possible to bring the axis of the object-glass in coincidence with axis of rotation of the stage (see, further, the detailed drawing at the side).

The instrument here described may be used in the first place as an ordinary microscope with magnifying power adapted to the special case in hand. In the second place, with polarizing prisms and the usual arrangement of lenses, it serves for determining the planes of light-vibration (like the *stauroscope* of Art. **328**); also for observing the interference-colors of doubly refracting sections and so on. Finally, with eyepiece removed and special condensing lenses added beneath the object on the stage (as more fully described later), it may be used, like the *conoscope*, for observing axial interference-figures, etc.

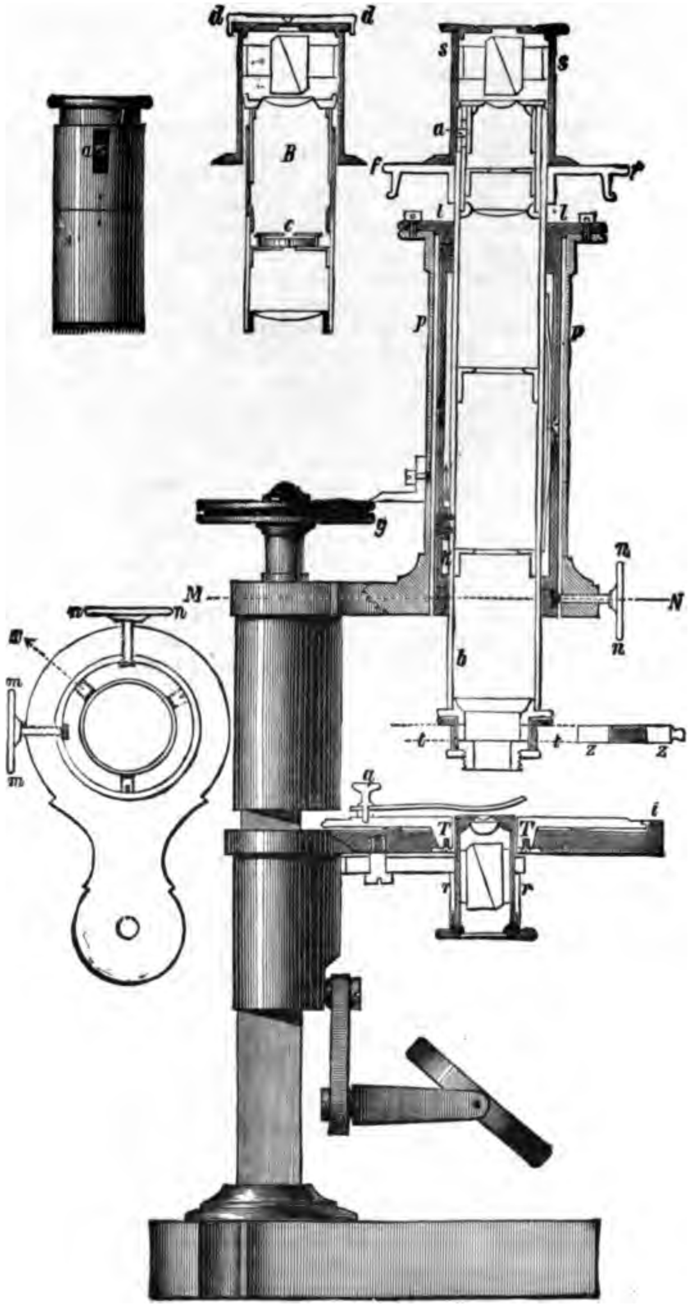
330. A later and improved form of microscope shown in Fig. 517 is essentially like that of Fig. 516, but has various refinements for accurate work. Thus, a screw is added for the coarse adjustment; another screw to raise and depress the lower nicol; a mechanical stage, etc. A more essential improvement is the insertion of the upper nicol in a support, *N*, which can be pushed in or out at will *between* the eyepiece and objective. The upper nicol above the eyepiece is, however, also needed in certain cases, for example with the Bertrand ocular, described later.

The microscope which has been briefly described is, as stated, especially applicable to the study of the form, optical properties, and mutual relations of minerals as they are found in thin sections of rocks; it has therefore become an important adjunct to geological research. It can also be used to great advantage in the study of small independent crystals

---

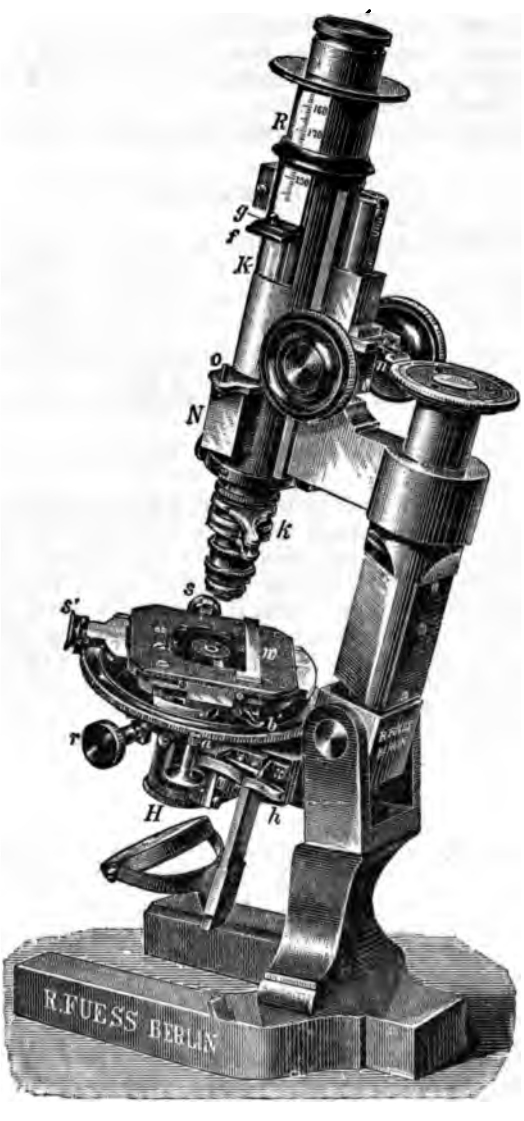
* See Rosenbusch, Mikr. Phys., 117–130, 1892; also Groth, Phys. Kryst., 733–756, 1895.

516.



and crystalline sections or fragments. The more important points to which the attention is to be directed, more particularly in the case of minerals in sections of rocks, are: (1) crystalline form, as shown in the outline; (2) direction of cleavage-lines; (3) refractive

517.



index; (4) light-absorption in different directions, *i.e.*, dichroism or pleochroism; (5) the isotropic or anisotropic character, and if the latter, the direction of the planes of light-vibration—this will generally decide the question as to the crystalline system; (6) position of the axial plane and nature of the axial interference-figures; (7) the strength and character (+ or −) of the double refraction; (8) inclusions, solid, liquid, or gaseous. The explanation in regard to the special optical points mentioned is deferred to later pages.

GENERAL OPTICAL CHARACTERS OF MINERALS.

331. There are certain characteristics belonging to all minerals alike, crystallized and non-crystallized, in their relation to light. These are:

1. DIAPHANEITY: depending on the relative quantity of light transmitted.
2. COLOR: depending on the kind of light reflected or transmitted, as determined by the selective absorption.
3. LUSTER: depending on the power and manner of reflecting light.

1. DIAPHANEITY.

332. Degrees of Transparency.—The amount of light transmitted by a solid varies in intensity, or, in other words, more or less light may be *absorbed* in the passage through the given substance (see Art. **307**). The amount of absorption is a minimum in a transparent solid, as ice, while it is greatest in one which is opaque, as iron. The following terms are adopted to express the different degrees in the power of transmitting light:

Transparent: when the outline of an object seen through the mineral is perfectly distinct.

Subtransparent, or *semi-transparent:* when objects are seen, but the outlines are not distinct.

Translucent: when light is transmitted, but objects are not seen.

Subtranslucent: when merely the edges transmit light or are translucent.

When no light is transmitted, even on the thin edges of small splinters, the mineral is said to be *opaque.* This is properly only a *relative* term, since no substance fails to transmit some light, if made sufficiently thin. Magnetite is translucent in the Pennsbury mica. Even gold may be beaten out so thin as to be translucent, in which case it transmits a greenish light.

The property of diaphaneity occurs in the mineral kingdom, in every degree from nearly perfect opacity to transparency, and many minerals present, in their numerous varieties, nearly all the different shades.

2. COLOR.

333. Nature of Color.—As briefly explained in Art. **294**, the sensation of color depends alone upon the length of the waves of light which meet the eye, if they are all of the same length. If the light consists of various wave-lengths, it is to the combined effect of these that the sensation of color is due.

Further, since the light ordinarily employed is essentially white light, that is, consists of all the wave-lengths corresponding to the successive colors of the spectrum, the color of a body depends upon the selective absorption (see Art. **307**) which it exerts upon the light transmitted or reflected by it. A yellow mineral, for instance, absorbs all the waves of the spectrum with the exception of those which together give the sensation of yellow. In general the color which the eye perceives is the result of the mixture of those waves which are not absorbed.

All minerals may be divided into two classes: (1) those whose color belongs to the finest particles mechanically made; and (2) those whose color in the state of fine powder is different from what it is in the mass.

To the first class belong the metals and many minerals having a metallic luster; for instance, the powder of the black magnetic oxide of iron, magnetite, is black; that of hematite, which, though often black on the surface, is red by transmitted light, is red, and so on.

To the second class belong the silicates, and in fact the large part of all minerals having an unmetallic luster. With them the color is often quite unessential, being generally due to small admixtures of some metallic oxide, to some carbon compound, or to some foreign substance in a finely divided state. With most of these, the fine powder is either white or light-colored; for example, the streak (Art. 334) of *black, green, red,* and *blue* tourmaline varies little from *white.*

334. Streak.—The color of the powder of a mineral as obtained by scratching the surface of the mineral with a knife or file, or still better, if not too hard, by rubbing it on an unpolished porcelain surface, is called the *streak.* It is obvious from the distinctions stated above that the streak is often a very important quality in distinguishing minerals. This is especially true with minerals of the first class mentioned above, that is, those with metallic luster, as defined in Art. 338.

335. Dichroism; Pleochroism.—The selective absorption, to which the color of a mineral is due, more especially by transmitted light, varies according to the molecular structure of the crystals. It is hence one of the special optical characters depending upon the crystallization, which are discussed later. Here belong *dichroism* or *pleochroism,* the property of exhibiting different colors in different directions by transmitted light. This subject is explained further in Arts. 365 and 393.

336. Varieties of Color.—The following eight colors were selected by Werner as fundamental, to facilitate the employment of this character in the description of minerals: *white, gray, black, blue, green, yellow, red,* and *brown.*

(*a*) The varieties of METALLIC COLORS recognized are as follows:

1. *Copper-red:* native copper.—2. *Bronze-yellow:* pyrrhotite.—3. *Brass-yellow:* chalcopyrite.—4. *Gold-yellow:* native gold.—5. *Silver-white:* native silver, less distinct in arsenopyrite.—6. *Tin-white:* mercury; cobaltite.—7. *Lead-gray:* galena, molybdenite.—8. *Steel-gray:* nearly the color of fine-grained steel on a recent fracture; native platinum, and palladium.

(*b*) The following are the varieties of NON-METALLIC COLORS:

A. WHITE. 1. *Snow-white:* Carrara marble.—2. *Reddish white,* 3. *Yellowish white* and 4. *Grayish white:* all illustrated by some varieties of calcite and quartz.—5. *Greenish white:* talc.—6. *Milk-white:* white, slightly bluish; some chalcedony.

B. GRAY. 1. *Bluish gray:* gray, inclining to dirty blue.—2. *Pearl-gray:* gray, mixed with red and blue; cerargyrite.—3. *Smoke-gray:* gray, with some brown; flint.—4. *Greenish gray:* gray, with some green; cat's-eye; some varieties of talc.—5. *Yellowish gray:* some varieties of compact limestone.—6. *Ash-gray:* the purest gray color; zoisite.

C. BLACK. 1. *Grayish black:* black, mixed with gray (without green, brown, or blue tints); basalt; Lydian stone.—2. *Velvet-black:* pure black; obsidian, black tourmaline.—3. *Greenish black:* augite.—4. *Brownish black:* brown coal, lignite.—5. *Bluish black:* black cobalt.

D. BLUE. 1. *Blackish blue:* dark varieties of azurite.—2. *Azure-blue:* a clear shade of bright blue; pale varieties of azurite, bright varieties of lazulite.—3 *Violet-blue:* blue, mixed with red; amethyst, fluorite.—4. *Lavender-blue:* blue, with some red and much gray.—5. *Prussian-blue,* or Berlin blue: pure blue; sapphire, cyanite.—6. *Smalt-blue:* some varieties of gypsum.—7. *Indigo-blue:* blue, with black and green; blue tourmaline.—8. *Sky-blue:* pale blue, with a little green; it is called mountain-blue by painters.

E. GREEN. 1. *Verdigris-green:* green, inclining to blue; some feldspar (amazon-stone).—2. *Celandine-green:* green, with blue and gray; some varieties of talc and beryl. It is the color of the leaves of the celandine (Chelidonium majus).—3. *Mountain-green:* green, with much blue; beryl.—4. *Leek-green:* green, with some brown; the color of leaves of garlic; distinctly seen in prase, a variety of quartz.—5. *Emerald-green:* pure deep green; emerald.—6. *Apple-green:* light green with some yellow; chrysoprase.—7. *Grass-green:* bright green, with more yellow; green diallage.—8. *Pistachio-green:* yellowish green, with some brown; epidote.—9. *Asparagus-green:* pale green, with much yellow; asparagus stone (apatite).—10. *Blackish green:* serpentine.—11. *Olive green:* dark green, with much brown and yellow; chrysolite.—12. *Oil-green:* the color of olive-oil; beryl, pitchstone.—13. *Siskin-green:* light green, much inclining to yellow; uranite.

F. YELLOW. 1. *Sulphur-yellow:* sulphur.—2. *Straw-yellow:* pale yellow; topaz.—3. *Wax-yellow:* grayish yellow with some brown; blende, opal.—4. *Honey-yellow:* yellow, with some red and brown; calcite.—5. *Lemon-yellow:* sulphur, orpiment.—6. *Ocher-yellow:* yellow, with brown; yellow ocher.—7. *Wine-yellow:* topaz and fluorite.—8. *Cream-yellow:* some varieties of lithomarge.—9. *Orange-yellow:* orpiment.

G. RED. 1. *Aurora-red:* red, with much yellow; some realgar.—2. *Hyacinth-red:* red, with yellow and some brown; hyacinth garnet.—3. *Brick-red:* polyhalite, some jasper.—4. *Scarlet-red:* bright red, with a tinge of yellow; cinnabar.—5. *Blood-red:* dark red, with some yellow; pyrope.—6. *Flesh-red:* feldspar.—7. *Carmine-red:* pure red; ruby sapphire.—8. *Rose-red:* rose quartz.—9. *Crimson-red:* ruby.—10. *Peachblossom-red:* red, with white and gray; lepidolite.—11. *Columbine-red:* deep red, with some blue; garnet.—12. *Cherry-red:* dark red, with some blue and brown; spinel, some jasper.—13. *Brownish-red:* jasper, limonite.

H. BROWN. 1. *Reddish brown:* garnet, zircon.—2. *Clove-brown:* brown, with red and some blue; axinite.—3. *Hair-brown:* wood-opal.—4. *Broccoli-brown:* brown, with blue, red, and gray; zircon.—5. *Chestnut-brown:* pure brown.—6. *Yellowish brown:* jasper.—7. *Pinchbeck-brown:* yellowish-brown, with a metallic or metallic-pearly luster; several varieties of talc, bronzite.—8. *Wood-brown:* color of old wood nearly rotten; some specimens of asbestus.—9. *Liver-brown:* brown, with some gray and green; jasper.—10. *Blackish brown:* bituminous coal, brown coal.

3. LUSTER.

337. Nature of Luster.—The luster of minerals varies with the nature of their surfaces. A variation in the quantity of light reflected produces different degrees of intensity of luster; a variation in the nature of the reflecting surface produces different kinds of luster.

338. Kinds of Luster.—The kinds of luster recognized are as follows:

1. METALLIC: the luster of the metals, as of gold, copper, iron, tin.

In general, a mineral is not said to have metallic luster unless it is opaque in the mineralogical sense, that is, it transmits no light on the edges of thin splinters. Some minerals have varieties with metallic and others with unmetallic luster; this is true of hematite.

Imperfect metallic luster is expressed by the term *sub-metallic*, as illustrated by columbite, wolframite. Other kinds of luster are described briefly as UNMETALLIC.

2. *Adamantine:* the luster of the diamond. When also sub-metallic, it is termed *metallic-adamantine*, as cerussite, pyrargyrite.

Adamantine luster belongs to substances of high refractive index. This may be connected with their relatively great density (and hardness), as with the diamond, also corundum, etc.; or because they contain heavy molecules, thus most compounds of lead, not metallic in luster, have a high refractive index and an adamantine luster.

3. *Vitreous:* the luster of broken glass. An imperfectly vitreous luster is termed *sub-vitreous*. The vitreous and sub-vitreous lusters are the most common in the mineral kingdom. Quartz possesses the former in an eminent degree; calcite, often the latter.

4. *Resinous:* luster of the yellow resins, as opal, and some yellow varieties of sphalerite.

5. *Greasy:* luster of oily glass. This is near resinous luster, but is often quite distinct, as elæolite.

6. *Pearly:* like pearl, as talc, brucite, stilbite, etc. When united with submetallic, as in hypersthene, the term *metallic-pearly* is used.

Pearly luster belongs to the light reflected from a pile of thin glass-plates; similarly it is exhibited by minerals, which, having a perfect cleavage, may be partially separated into successive plates, as on the basal plane of apophyllite. It is also shown for a like reason by foliated minerals, as talc and brucite.

7. *Silky:* like silk; it is the result of a fibrous structure. Ex. fibrous calcite, fibrous gypsum.

The different degrees and kinds of luster are often exhibited differently by unlike faces of the same crystal, but always similarly by like faces. The lateral faces of a right square prism may thus differ from a terminal, and in the right rectangular prism the lateral faces also may differ from one another. For example, the basal plane of apophyllite has a pearly luster wanting in the prismatic faces, they having a vitreous luster.

As shown by Haidinger, only vitreous, adamantine, and metallic luster belong to faces perfectly smooth and pure. In the first, the refractive index of the mineral is 1·3–1·8; in the second, 1·9–2·5; in the third, about 2·5. The true difference between metallic and vitreous luster is due to the effect which the different surfaces have upon the reflected light; in general, the luster is produced by the union of two simultaneous impressions made upon the eye. If the light reflected from a metallic surface be examined by a nicol prism (or the dichroscope of Haidinger, Art. 365), it will be found that both rays, that vibrating in the plane of incidence and that whose vibrations are normal to it, are alike, each having the color of the material, only differing a little in brilliancy; on the contrary, of the light reflected by a vitreous substance, those rays whose vibrations are at right angles to the plane of incidence are more or less polarized, and are colorless, while those whose vibrations are in this plane, having penetrated somewhat into the medium and suffered some absorption, show the color of the substance itself. A plate of red glass thus examined will show a colorless and a red image. Adamantine luster occupies a position between the others.

339. Degrees of Luster.—The *degrees of intensity* of luster are denominated as follows:

1. *Splendent:* reflecting with brilliancy and giving well-defined images, as hematite, cassiterite.

2. *Shining:* producing an image by reflection, but not one well-defined, as celestite.

3. *Glistening:* affording a general reflection from the surface, but no image, as talc, chalcopyrite.

4. *Glimmering:* affording imperfect reflection, and apparently from points over the surface, as flint, chalcedony.

A mineral is said to be *dull* when there is a total absence of luster, as chalk, the ochers, kaolin.

340. Play of Colors. Opalescence. Iridescence.—The term *play of colors* is used to describe the appearance of several prismatic colors in rapid succession on turning the mineral. This property belongs in perfection to the diamond, in which it is due to its high dispersive power. It is also observed in precious opal, where it is explained on the principle of interference; in this case it is most brilliant by candle-light.

The expression *change of colors* is used when each particular color appears to pervade a larger space than in the play of colors and the succession produced by turning the mineral is less rapid. This is shown in labradorite, as explained under that species.

Opalescence is a milky or pearly reflection from the interior of a specimen. Observed in some opal, and in cat's-eye.

Iridescence means the exhibition of prismatic colors in the interior or on the surface of a mineral. The phenomena of the play of colors, iridescence, etc., are sometimes to be explained by the presence of minute foreign crystals, in parallel positions; more generally, however, they are caused by the presence of fine cleavage-lamellæ, in the light reflected from which interference takes place, analogous to the well-known Newton's rings (see Art. 313).

341. Tarnish—A metallic surface is tarnished when its color differs from that obtained by fracture, as is the case with specimens of bornite. A surface possesses the *steel tarnish* when it presents the superficial blue color of tempered steel, as columbite. The tarnish is *irised* when it exhibits fixed prismatic colors, as is common with the hematite of Elba. These tarnish and iris colors of minerals are owing to a thin surface or film, proceeding from different sources, either from a change in the surface of the mineral or from foreign incrustation; hydrated iron oxide, usually formed from pyrite, is one of the most common sources of it, and produces the colors on anthracite and hematite.

342. Asterism.—This name is given to the peculiar star-like rays of light observed in certain directions in some minerals. This is seen by reflected light in the form of a six-rayed star in sapphire, and is also well shown by transmitted light (as of a small flame) with the phlogopite mica from South Burgess, Canada. In the former case it is explained by the presence of thin twinning-lamellæ symmetrically arranged. In the other case it is due to the presence of minute inclosed crystals, also symmetrically arranged, which are probably rutile or tourmaline in most cases. Crystalline faces which have been artificially etched also sometimes exhibit asterism. The peculiar light-figures sometimes observed in reflected light on the faces of crystals, either natural or etched, are of similar nature.

343. Schillerization.—The general term *schiller* (from the German) is applied to the peculiar luster, sometimes nearly metallic, observed in definite directions in certain minerals, as conspicuously in schiller-spar (an altered variety of bronzite), also in diallage, hypersthene, sunstone, and others. It is explained by the reflection either from minute inclosed plates in parallel position or from the surfaces of minute cavities (negative crystals) having a common orientation. In many cases it is due to alteration which has developed these bodies (or the cavities) in the direction of solution-planes (see Art. 264). The process by which it has been produced is then called *schillerization.*

344. Fluorescence.—The emission of light from within a substance while it is being exposed to direct radiation, or in certain cases to an electrical discharge in a vacuum tube, is called *fluorescence.* It is best exhibited by fluorite, from which the phenomenon gained its name. Thus, if a beam of white light be passed through a cube of colorless fluorite a delicate violet color is called out in its path. This effect is chiefly due to the action of the ultra-violet rays, and is connected with a change of refrangibility in the transmitted light.

The electrical discharge from the negative pole of a vacuum tube calls out a brilliant fluorescence not only with the diamond, the ruby, and many gems, but also with calcite and other minerals. Such substances may continue to emit light, or *phosphoresce,* after the discharge ceases.

345. Phosphorescence.—The *continued* emission of light by a substance (not incandescent) produced especially after heating, exposure to light or to an electrical discharge, is called *phosphorescence.*

Fluorite becomes highly phosphorescent after being heated to about 150° C. Different varieties give off light of different colors; the *chlorophane* variety, an emerald-green light; others purple, blue, and reddish tints. This phosphorescence may be observed in a dark place by subjecting the pulverized mineral to a heat below redness. It is even called out by a sharp blow with a hammer. Some varieties of white limestone or marble, after slight heating, emit a yellow light; so also tremolite, danburite, and other species.

By the application of heat minerals lose their phosphorescent properties. But on passing electricity through the calcined mineral a more or less vivid light is produced at the time of the discharge, and subsequently the specimen when heated will often emit light as before. The light is usually of the same color as previous to calcination, but occasionally is quite different. It is in general less intense than that of the unaltered mineral, but is much increased by a repetition of the electric discharges, and in some varieties of fluorite it may be nearly or quite restored to its former brilliancy. It has also been found that some varieties of fluorite, and some specimens of diamond, calcite, and apatite, which are not naturally phosphorescent, may be rendered so by means of electricity. Electricity will also increase the natural intensity of the phosphorescent light.

Exposure to the light of the sun produces very apparent phosphorescence with many diamonds, but some specimens seem to be destitute of this power. This property is most striking after exposure to the blue rays of the spectrum, while in the red rays it is rapidly lost.

LITERATURE.

Asterism.

Rose. Mica. Ber. Ak. Berlin, 614, 1862; 344, 1869.
Fr. von Kobell. Ber. Ak. München, 65, 1863.
Baumhauer. Calcite. Pogg. Ann., **138**, 563, 1869; **139**, 34; **140**, 271, 1870.
Tschermak. Phlogopite. Zs. Kr., **2**, 36, 1877.
Lacroix. Phlogopite. Bull. Soc. Min., **8**, 99, 1885; **12**, 314, 1889.

Schiller.

Scheerer. Sunstone. Pogg. Ann., **64**, 153, 1845.
Haidinger. Pogg. Ann., **70**, 574; **71**, 321, 1847; **76**, 99, 1849.
Reusch. Pogg. Ann., **116**, 392, 1862; **118**, 256, 1863; **120**, 95, 1863.

See also papers on labradorite by Reusch, Schrauf, Vogelsang; on hypersthene, by Kosmann, referred to on p. 142; further papers by Judd (p. 155).

Fluorescence, Phosphorescence.

Becquerel. Ann. Ch. Phys., **55**, 5–119, 1859.
H. Rose. Pogg. Ann., **35**, 481, 1835.
Stokes. Phil. Trans., **142**, 463, 1852; **143**, 385, 1853. **(Also in Pogg. Ann., 96, 523, 1855; Erg.-Bd., 4. 188, 1854.)**

Also many other memoirs.

SPECIAL OPTICAL CHARACTERS BELONGING TO CRYSTALS OF THE DIFFERENT SYSTEMS.

346. All crystallized minerals may be grouped into three grand classes, which are distinguished by their physical properties, as well as their geometrical form. These three classes are as follows:

A. *Isometric class*, embracing crystals of the isometric system, which are referred to three equal rectangular axes.

B. *Isodiametric class*, embracing crystals of the tetragonal and hexagonal systems, referred to two, or three, equal lateral axes and a third, or fourth, axis unequal to them at right angles to their plane. Crystals of this class have a fixed principal axis of crystallographic symmetry.

C. *Anisometric class*, embracing the crystals of the orthorhombic, monoclinic, and triclinic systems, referred to three unequal axes. Crystals of this class are without a fixed axis of crystallographic symmetry.

347. Isotropic Crystals.—Of the three classes, the ISOMETRIC CLASS includes all crystals which, with respect to light and related phenomena involving the ether, are *isotropic;* that is, those which have like optical properties in all directions. Specifically, a light-wave is propagated in them with the same velocity in all directions, and its wave-front is therefore a sphere. Hence, also, the sphere may be regarded as representing the optical structure of an isometric crystal. The geometrical property of the sphere that every cross-section is a circle corresponds to the optical property of the isotropic medium in which the velocity of light-propagation is the same in every direction, for this being true, the medium must have like properties of the ether in any plane normal to such a line.

It must be repeated here, however, that such a crystal is *not* isotropic with reference to those characters which depend directly upon the molecular structure alone, as cohesion and elasticity. (See Art. **254.**)

Further, amorphous bodies, as glass and opal, which are destitute of any oriented molecular structure—that is, those in which all directions are sensibly the same—are also isotropic, and not only with reference to light, but also as regards their strictly molecular properties.

348. Anisotropic Crystals; Uniaxial and Biaxial.—Crystals of the ISODIAMETRIC and ANISOMETRIC CLASSES, on the other hand, are in distinction *anisotropic.* Their optical properties are in general unlike in different directions, or, more particularly, the velocity with which light is propagated varies with the direction.

Further, in crystals of the isodiametric class that variable property of the light-ether upon which the velocity of propagation depends remains constant for all directions which are normal, or, again, for all those equally inclined to the vertical crystallographic axis. In the direction of this axis there is no double refraction; it is hence called the *optic axis*, and the crystals of this class are said to be *uniaxial.* The optical structure of uniaxial crystals can be represented by a spheroid, that is, an ellipsoid of revolution whose axis of revolution is the optic axis, or axis of crystallographic symmetry. The direction and properties of this optic axis will be seen to correspond to the geometrical property of the spheroid, a section of which normal to this axis is always a circle.

Crystals of the third or anisometric class have more complex optical relations requiring special explanation, but in general it may be stated that in them there are always two directions analogous in character to the single optic axis spoken of above, hence these crystals are said to be optically *biaxial.* Further, it will be shown that their optical structure may be represented geometrically by an ellipsoid with three unequal rectangular axes. Every such ellipsoid has two directions in which it can be cut yielding cross-sections which are circles; the optic axes spoken of will be seen later to be normal to these planes after the analogy of uniaxial crystals.

In crystals of the orthorhombic system the axes of the ellipsoid coincide in direction with the crystallographic axes. In crystals of the monoclinic system one of these ellipsoidal axes coincides with the axis of crystallographic symmetry, the other two lie in the plane of symmetry. In crystals of the triclinic system there is no necessary relation between the position of the ellipsoidal axes and those assumed to describe the crystallographic form.

All of these points require detailed discussion, but the above statements will partially serve to bring out the intimate connection between the molecular structure exhibited in the geometrical form and the optical characters depending upon the properties belonging to the light-ether within the crystal.

A. ISOMETRIC CRYSTALS.

349. It has been stated that crystals of the isometric system are optically *isotropic*, and hence light travels with the same velocity in every direction in them. Light can, therefore, suffer only single refraction in passing into an isotropic medium; or, in other words, there can be but one value of the refractive index for a given wave-length. If this be represented by n, while V is the velocity of light in air and v that in the given medium, then

$$n = \frac{V}{v}, \text{ or } v = \frac{V}{n}.$$

The wave-front for light-waves propagated from any point within such an isotropic medium is a sphere, and, as already stated, this geometrical figure may be taken as representing the optical structure of an isometric crystal.

This statement holds true of all the groups of isometric crystals. In other words, a crystal of maximum symmetry, as fluorite, and one having the restricted symmetry characteristic of the tetrahedral or pyritohedral divisions, have alike the same isotropic character. Two of the groups, however, namely the plagihedral and the tetartohedral groups, differ in this particular: that crystals belonging to them may exhibit what has already been defined (Art. 323) as circular polarization.

350. Behavior of Sections of Isometric Crystals in Polarized Light.—In consequence of their isotropic character, isometric crystals exhibit no special phenomena in polarized light. Sections of transparent isometric crystals may be always recognized as such by the fact that they behave as an amorphous substance in polarized light. In other words, a section on the stage of the polarization-microscope, when the nicols are crossed, appears dark, and a revolution of the section in any plane produces no change in appearance. Similarly, it appears light in any position when placed between parallel nicols. Some anomalies are mentioned on a later page (Art. 411).

The single refractive index may be determined by means of a prism cut with its edge in any direction whatever.

B. UNIAXIAL CRYSTALS.

General Optical Relations.

351. The crystallographic and optical relations of crystals belonging to crystals of the tetragonal and hexagonal systems have already been briefly summarized (Art. **348**); it now remains to develop their optical characters more fully. This can be done most simply by making frequent use of the familiar conception of a light-ray to represent the character and motion of the light-wave.

352. Optic Axis. Ordinary and Extraordinary Ray.—The study of a crystal belonging to this class shows, in the first place, that light-rays which pass in the direction of the vertical axis suffer no double refraction. This direction is that called the *optic axis.* Since the rays spoken of are propagated by vibrations at right angles to the vertical axis, that is, in the plane of the lateral crystallographic axes, this observed fact proves that for such rays there is but one value of the refractive index, and, further, that all the lateral directions must be identical so far as those properties of the ether are concerned upon which the velocity of light depends.

On the other hand, light which passes through the crystal in any other direction than that of the vertical axis suffers *double refraction*; in other words, it is separated into two rays, which are propagated with different velocities. This is true (see Art. 310) even when the rays follow the same path, as in the case of perpendicular incidence upon the given face.

Both of these rays are completely polarized, and that in planes at right angles to each other.

It is found, further, that for one of these two rays, namely, that propagated by vibrations normal to the vertical axis, there is a constant value of the refractive index, whatever its direction; moreover, this value follows the usual law as to the constant ratio between the sines of the angles of incidence and refraction (Art. **298**). It is hence called the *ordinary ray,* and the corresponding refractive index is uniformly represented by the letter ω.

For the other ray, on the other hand, it is found that the refractive index varies, and in general it does not obey the sine law. It is hence called the *extraordinary ray.* Further, if the direction of propagation changes progressively from that nearly coinciding with the vertical axis to that in the lateral plane normal to it, it is found that the value of the refractive index of the extraordinary ray deviates more and more widely from the constant value for the ordinary ray, and this difference becomes a maximum when the former is propagated in a lateral plane normal to the vertical axis, that is, by transverse vibrations in the direction of this axis. This last value of the refractive index is represented by the letter ϵ. These two indices, ω and ϵ, are called the *principal indices* of a uniaxial crystal. A *principal section* of a uniaxial crystal is a section passing through the vertical axis.

353. Positive and Negative Crystals.—Uniaxial crystals are divided into two classes. Those in which the refractive index of the extraordinary ray, ϵ, is greater than that of the ordinary ray, ω, are called *positive.* This is illustrated by quartz for which (for yellow sodium light):

$$\omega = 1{\cdot}544. \qquad \epsilon = 1{\cdot}553.$$

On the other hand, if ω is greater than ϵ, the crystal is said to be *negative.* Calcite is an example, for which (for sodium light):

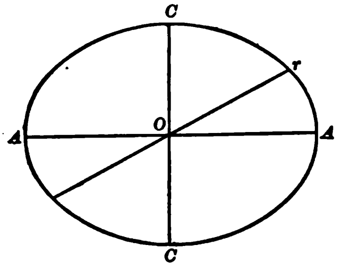
$$\omega = 1{\cdot}658. \qquad \epsilon = 1{\cdot}486.$$

Other examples are given later (Art **356**).

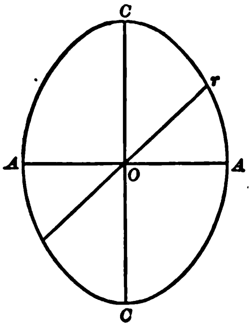
354. Wave-surface.—Remembering that the velocity of light-propagation is always inversely proportional to the corresponding refractive index, it is obvious that the velocity of the ordinary ray for all directions in a uniaxial crystal must be the same, being uniformly proportional to $\frac{1}{\omega}$. In other words, the wave-front of the ordinary ray must be a sphere.

For the extraordinary ray, however, the velocity varies with the direction, being proportional to $\frac{1}{\epsilon}$ in a lateral direction and becoming sensible equal to $\frac{1}{\omega}$ when nearly coincident with the direction of the vertical axis. The law of the varying change of velocity between these values, $\frac{1}{\omega}$ and $\frac{1}{\epsilon}$ is given by an ellipse whose axes (*OC*, *OA*, Figs. 518, 519) are respectively proportional to the above values.

518.



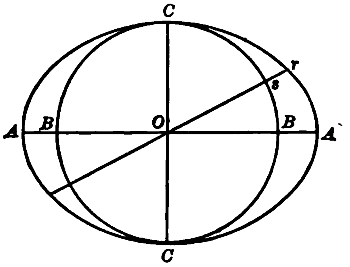
519.



$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon} = \epsilon : \omega.$$

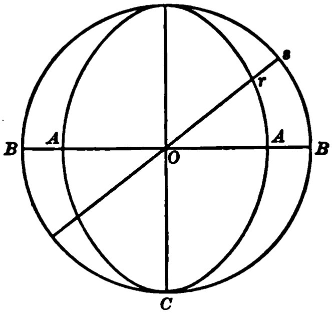
This law, suggested by Huygens, has since been verified by accurate experiments by several observers for typical substances, as calcite and soda niter; hence it is accepted without question as a law of nature. The wave-front of the extraordinary ray is then a spheroid, or an ellipsoid of revolution whose axis coincides with the vertical crystallographic axis, that is, the optical axis. In the direction of the vertical axis it is obvious that the two wave-fronts coincide.

520.



Negative crystal, $\omega > \epsilon$.

521.

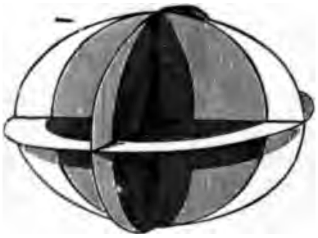


Positive crystal, $\epsilon > \omega$.

Figures 520 and 521 represent vertical sections of the combined wave-surfaces for both rays. Fig. 520 gives that for a *negative* crystal like calcite

($\omega > \epsilon$); Fig. 521 that of a *positive* crystal like quartz ($\epsilon > \omega$). Fig. 522 is an attempt to show the relations of the two wave-fronts of a negative crystal in perspective.[*] The constant value of the velocity of the ordinary ray $\left(\frac{1}{\omega}\right)$, whatever its direction in this plane, is expressed by the radius of the circle ($= OC$). On the other hand, the velocity of the extraordinary ray in the lateral direction is given by $OA\left(\frac{1}{\epsilon}\right)$, while in a direction as *Osr*, Fig. 520 (*Ors*, Fig. 521), it is expressed by the length of this line, becoming more and more nearly equal to $OC\left(\frac{1}{\omega}\right)$ as its direction approaches that of the vertical axis.

522.

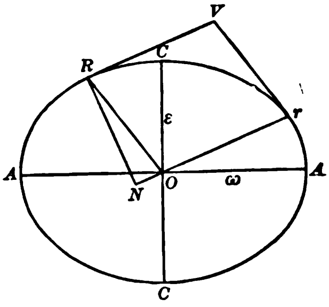


355. Indicatrix.—It will now be understood what was meant by the statement in Art. **348** that the optical structure of a uniaxial crystal may be represented by an ellipsoid of revolution, and it is further obvious that the ratio between the axes of this ellipsoid must be as already given:

$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon}, \quad \text{or} \quad \epsilon : \omega.$$

It has been shown by Fletcher[†] that this ellipsoid, called by him the indicatrix, may be taken to represent the optical characters of both rays without reference to the wave-surface, since it can be proved geometrically[‡] that for a given direction, as *Or*, the velocity of the extraordinary ray is expressed not only by *Or* but also by the inverse of the normal upon it from the point *R* (determined by the tangents to the ellipse), that is, by $\frac{1}{RN}$; also this normal fixes the plane of polarization which is perpendicular to *RN*. Further, the velocity of the ordinary ray, having the same direction (cf. p. 195), is expressed by the inverse of the second normal upon the same line, that is, $\frac{1}{OA}$, since this normal is always in the equatorial plane, the section of which is a circle. Fig. 523 shows the form of the indicatrix for a negative crystal

523.



---

[*] Figs. 522 and 588 are taken from Müller-Pouillet's Lehrbuch der Physik.

[†] The Optical Indicatrix and the Transmission of Light in Crystals, by L. Fletcher, London, 1892.

[‡] This follows, from the property of the ellipse in general, since the parallelogram $ORVr = OA.OC$, that is, $RN.Or = OA.OC$ and $Or = \frac{OA.OC}{RN}$. $\therefore Or = \frac{\text{Constant}}{RN}$.

In other words, the velocity of the extraordinary ray (v_e) varies inversely as $\frac{1}{RN}$.

Similarly, v_ω is represented by Or_1, that is, in the indicatrix by

$$\frac{1}{OA}\left(\text{since } Or_1 = OC = \frac{OA.OC}{OA} = \frac{\text{Constant}}{OA}\right).$$

like calcite ($\omega > \epsilon$); that for a positive crystal, like quartz ($\epsilon > \omega$) would be a prolate spheroid.

356. Examples of Positive and Negative Crystals.—The following lists give prominent positive and negative uniaxial crystals, with the values of the refractive indices, ω and ϵ, for each, corresponding to yellow sodium light.* The difference between these, $\omega-\epsilon$ or $\epsilon-\omega$, is also given; this measures the birefringence or *strength* of the double refraction.

It may be remarked that in some species both + and − varieties have been observed. Certain crystals of apophyllite are positive for one end of the spectrum and negative for the other, and consequently for some color between the two extremes it has no double refraction. The same is true for some other species (*e.g.*, chabazite) of weak double refraction. It is to be noted also that while eudialyte is positive, the related eucolite is negative.

NEGATIVE CRYSTALS.

	ω	ϵ	$\omega-\epsilon$
Proustite..............	3·0877	2·7924	0·2958
Calcite.................	1 6585	1·4863	0·1722
Tourmaline............	1·6397	1·6208	0·0189
Corundum............	1·7675	1·7592	0·0083
Beryl...................	1·5894	1·5821	0·0073
Nephelite..............	1·5416	1·5376	0·0040
Apatite.................	1·6461	1·6417	0·0034
Vesuvianite............	1·7235	1·7226	0·0009

POSITIVE CRYSTALS.

	ω	ϵ	$\epsilon-\omega$
Rutile	2·6158	2·9029	0·2871
Cassiterite.............	1·9966	2·0934	0·0968
Zircon..................	1·9313	1·9931	0·0618
Phenacite..............	1·6540	1·6697	0·0157
Brucite.................	1·5590	1·5795	0·0205
Quartz.................	1·5442	1·5533	0·0091
Apophyllite...........	1·5337	1·5356	0 0019
Leucite................	1·508	1·509	0·001

Examination of Uniaxial Crystals in Polarized Light.

357. Section Normal to the Axis in Parallel Polarized Light.—Suppose a section of a uniaxial crystal to be cut perpendicular to the vertical axis. It has already been shown that light passing through the crystal in this direction suffers no double refraction; consequently, such a section examined in *parallel* polarized light in the instrument called an orthoscope (Fig. 515), or in the polarization-microscope (Figs. 516, 517), behaves as a section of an isometric crystal, or of an amorphous substance. If the nicols are crossed it appears *dark*, and remains so when revolved.

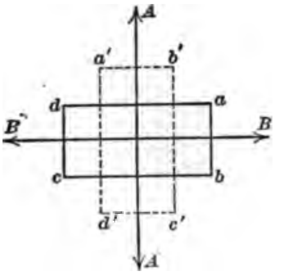
358. Section Parallel to the Axis.—A section cut parallel to the vertical axis, as already explained, has two directions of light-vibration, one parallel to this axis and the other at right angles to it. A ray of ordinary light falling upon such a section at right angles is divided into the two rays, ordinary and extraordinary, which, however, in this special case of perpendicular incidence travel on in the same path through the crystal, but one of them retarded relatively to the other. In parallel polarized light between crossed nicols such a section will appear dark if the directions of its two vibration-planes coincide with the vibration-planes of the nicols. Thus in Fig. 524, *AA* being the vibration-plane of the lower nicol (polarizer) and *BB* of the upper nicol (analyzer), the light that has passed through the polarizer has its vibrations limited to the plane *AA*; these, therefore, pass through the section *abcd*, but they are arrested or extinguished by the second nicol. The same will be true if the section is turned at right angles to the first position, that is, into the position *a'b'c'd'*, represented by the dotted lines.

---

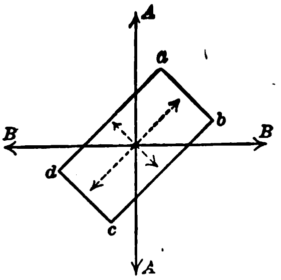
* For authorities, see Dana's System, 1892. For corundum and brucite the values of ω_r and ϵ_r are given.

If the section stand obliquely, as *abcd* in Fig. 525, it will appear light to the eye (and usually colored). For the vibrations parallel to *AA* that have passed through the polarizer have upon resolution a component in the direction of each of the vibration-planes of the section. Again, each of these components can be resolved along the direction of the vibration-plane of the upper nicol, *BB*. Therefore, two rays will emerge from the analyzer, both having the same vibration-plane, but one more or less retarded with reference to the other, the amount of retardation increasing with the birefringence and the thickness of the section. In general, therefore, these rays will interfere, and if the thickness of the section is sufficient (and not too great) it will appear colored in white light and, supposing the thickness uniform, of the same color throughout.

524.



525.



Any section whatever of a uniaxial crystal appears dark between crossed nicols if its principal section (Art. **352**) coincides with the vibration-plane of either nicol.

359. Color of a Section in Parallel Polarized Light. Birefringence.—The interference-color of a section under examination depends (Art. **320**) upon its thickness and upon the birefringence; this birefringence has a maximum value, equal to $\omega - \epsilon$ or $\epsilon - \omega$, if the section is cut parallel to the optic axis (*i.e.*, ∥ $\dot{c}$).

The following table* gives the thickness (in millimeters) of sections of a few uniaxial crystals which yield *red* of the first order:

	Birefringence ($\omega - \epsilon$) or ($\epsilon - \omega$).	Thickness in Millimeters.
Rutile	0·287	0·0019
Calcite	0·172	0·0032
Zircon	0·062	0·0089
Tourmaline	0·023	0·0240
Quartz	0 009	0·0612
Nephelite	0·004	0·1377
Leucite	0·001	0·5510

---

* See further, Rosenbusch (Mikr. Phys. Min., 1892, p. 166), from whom these are taken. Compare also remarks made in Art. 320.

Again, as another example, it may be noted that with zircon ($\epsilon - \omega = 0·062$), a thickness of about 0·009 mm gives red of the first order; of 0·017 red of the second order; of 0·026 red of the third order.

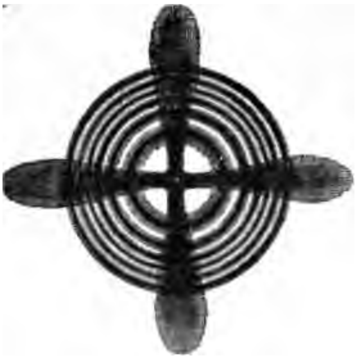
The methods ordinarily used to determine the birefringence of a section (not ⊥ ċ) of a uniaxial crystal, as also to fix the relative value of its two vibration-directions, are the same as those employed for biaxial crystals, and the discussion of them is postponed to a later page (Art. 384).

360. Uniaxial Interference-figure.—If an axial section, that is, one cut normal to the vertical axis ċ, of suitable thickness, be viewed in *converging* polarized light in a polariscope, *e.g.*, the conoscope (Art. 327, Fig. 514), or the tourmaline tongs (Fig. 513), or again in the microscope* arranged for the purpose, it no longer appears dark. On the contrary, a beautiful phenomenon is observed: a symmetrical black cross—when the nicols or tourmaline plates are crossed—with a series of concentric rings, dark and light in monochromatic light, but in white light showing the prismatic colors in succession in each ring. This is represented without the colors in Fig. 526, and with the colors in Fig. 1 of the plate forming the frontispiece to this volume.

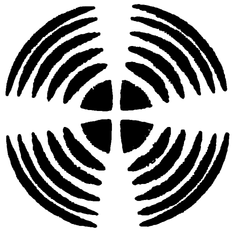
This cross becomes white when the nicols or tourmalines are in a parallel position, and each band of color in white light changes to its complementary tint (cf. Fig. 527). These interference-figures, seen † in this form only in a plate cut perpendicular to the vertical axis, mark the *uniaxial* character of the crystal.

The explanation of this phenomenon, so far as it can be given in a brief statement, is as follows: All the rays of light perpendicular to the plane of the section, that is, those whose vibrations coincide sensibly with the vibration-planes of either of the crossed nicols, must necessarily be extinguished. This gives rise to the black cross in the center, with its arms in the direction of the planes mentioned. Obviously this cross will be darkest along its central axis, while it fades out on the sides. All other rays passing through the given plate *obliquely* are doubly refracted, and after passing through the second nicol, thus being referred to the same plane of polarization, they *interfere*, and give rise

526.



527.



---

* After the section is in position on the stage, and properly focused, the eye-piece is removed and a condensing lens inserted over the lower nicol. It is important to use a relatively high-power objective. It is also possible to see axial figures without removing the eye-piece by using a magnifying glass above the latter. Cf. Klein. Jb. Min., Beil.-Bd., 3, 540, 1885; also Bertrand, Bull. Soc. Min., 1, 22, 96, 1878; 3, 97, 1880.

† Uniaxial crystals which produce circular polarization exhibit an axial interference-figure (Fig. 2 of the plate referred to above) which differs somewhat from that described, as noted in Art. 366. Some anomalies are mentioned later. (Art. 411.)

to a series of concentric rings, light and dark in monochromatic light, but in ordinary light showing the successive colors of the spectrum. The phenomenon is closely analogous to that of the Newton's rings mentioned in Art. 313. A cone of converging rays passes through the crystal and, having traversed the second nicol, each is divided into two rays with common vibration-planes, but one of them (the ordinary ray in positive crystals) slightly *retarded* with reference to the other. When the amount of retardation is equal to a wave-length (supposing monochromatic light to be employed) the effect of the interference is to destroy the light and the plane section of the cone, or circle, appears dark. Other dark rings are seen at distances which correspond to a retardation of $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, etc., of a wave-length. If, however, the retardation amounts to a whole wave-length or any multiple of this, the two rays unite to strengthen each other and give rise to a light ring. If ordinary white light is employed, the relations are similar but the retardation cones overlap because of the different values of the refractive indices (*i.e.*, velocities) for the different wave-lengths, and the series of colored circles is the result.

The distance of each successive ring from the center obviously depends upon the birefringence, or the difference between the refractive indices for the ordinary and extraordinary ray, and also upon the thickness of the plate. The stronger the double refraction and the thicker the plate, the smaller the angle of the light-cone which will give a certain amount of retardation, or, in other words, the nearer the circles will be to the center. Further, for the same section the circles will be nearer for blue light than for red, because of their shorter wave-length. When the thickness of the plate is considerable, only the black brushes are distinctly seen.

361. Determination of the Refractive Indices.—A single prism suffices for the measurement of the indices of refraction, ω and ϵ, with the refractometer. Further, its edge may be either parallel to the vertical axis or at, right angles to this direction. Such a prism yields two images of the slit, one corresponding to the ordinary and the other to the extraordinary ray, and for each the angle of minimum deviation is to be determined, that is, the angle δ in the general formula of Art. 304. Which of the two rays corresponds to the ordinary and which to the extraordinary ray can be easily distinguished by means of a nicol, the position of whose vibration-plane is known. This will extinguish that ray whose vibrations take place in a plane at right angles to its own vibration-plane.

362. Other Methods for Determining the Refractive Indices.—The method of total reflection (Arts. 303 and 325) may also be employed to determine the values of ω and ϵ. The section taken of a uniaxial crystal has its surface most conveniently parallel to the vertical axis. It is so placed that the direction normal to the optic axis is horizontal. The light is here separated into two rays, having separate limiting surfaces, and with a nicol prism it is easy to determine which of them corresponds to the vibrations parallel and perpendicular, respectively, to the optic axis.

Again, it is possible to obtain the refractive indices with considerable accuracy from measurements, in the plane of the axes, of the distances between the black rings in the interference-figures as seen in homogeneous light. The relation between these distances and the optical "axes of elasticity" was established by Neumann (Pogg. Ann., 33, 257, 1834). Bauer has also developed the same method as applied to uniaxial crystals, and employed it in the case of brucite (Ber. Ak. Berlin, 1877, 704, and 1881, 958).

With the polarization-microscope the most simple method is that of the

Duke de Chaulnes, explained in Art. **326**; this requires, however, that the two quantities measured should be determined with a considerable degree of accuracy, if the result is to be more than an approximation. (Cf. further, Rosenbusch, Mikr. Phys., p. 155 *et seq.*, 1892.)

363. Determination of the Positive or Negative Character.—The most obvious way of determining the character of the double refraction ($\epsilon > \omega$ or $\omega > \epsilon$) is to measure the refractive indices in accordance with the principles explained in the preceding articles. It is not always possible, however, to obtain a prism suitable for this purpose, and in any case it is convenient to have a more simple method of accomplishing the result.

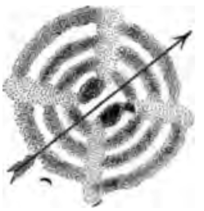
In the case of uniaxial crystals, the method which is practically the most simple is that suggested by Dove—the use of a cleavage plate of muscovite of such thickness that the two rays in passing through suffer a difference of phase which is equal to a quarter wave-length, or an odd multiple of this. It is often called a quarter-undulation plate (see Art. **322**).

Suppose that the section of the crystal to be examined, cut perpendicular to the axis, is brought between the crossed nicols in the polariscope; the black cross and the concentric colored rings are of course visible. Let now, while the given section occupies this position, the mica plate be placed over it, with the plane of its optic axes (determined beforehand, and the direction marked by a line for convenience) making an angle of 45° with the vibration-planes of the nicols. The interference-figure is completely transformed. The colored rings are broken by two more or less distinct hyperbolic brushes which pass through two black spots near the center, while the rings in the corresponding quadrants are pushed out from the center, and in the two remaining pushed in.

If now the line joining the two dark spots is at right angles to the axial plane of the mica (shown in the figures by the arrow) the crystal under experiment is opposite in refractive character to the mica, that is, *positive* (Fig. 529); if this line coincides with axial direction, the crystal is like the mica, *negative* (Fig. 530).

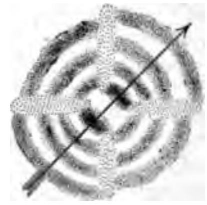
529.

+



530.

−



364. With the microscope the above method may also be employed, the mica plate, usually in the form of a narrow strip whose elongation is that of the plane of the optic axes, being introduced through a slit in the tube between the section and the analyzer. Here, however, the field of view is smaller than in the polariscope, and the black dots are not always distinctly observed; this is particularly true if the section be very thin or the mineral of low birefringence. In such cases a selenite plate is conveniently employed. This is of such thickness as to give a red of the first order, and the direction of elongation usually corresponds to the axis $\mathfrak{a}$ (Art. **373**). The plate is inserted in the tube with its axes inclined 45° to the vibration-planes of the nicols. This serves to increase the retardation between the two rays traversing the sections in two alternate quadrants and to diminish this in the others; the effect being shown by the rise or fall of the interference-colors, as compared with the usual scale (Art. **320**). For example, two blue areas (second order) may be seen in two opposite quadrants and two yellow (first order) in the others. The blue areas here correspond in position to the black dots in Figs. 529 and 530; hence if the line joining them is transverse to that of the axis ($\mathfrak{a}$) of the selenite plate the mineral is positive; if it coincides with it the mineral is negative.

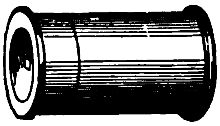
365. Absorption Phenomena of Uniaxial Crystals. Dichroism.—In uniaxial crystals it has been seen that there are two distinct values for the velocity of light transmitted by them, according as the vibrations take place *parallel* or at *right angles* to the vertical axis. Similarly the crystal may exert different degrees of absorption upon the rays transmitted by vibrations in these two directions. For example, a transparent crystal of zircon looked through in the direction of the vertical axis appears of a pinkish-brown color, while in a lateral direction the color is asparagus-green. This is because the rays (extraordinary) vibrating *parallel* to the axis are absorbed with the exception of those which together give the green color, and those vibrating *laterally* (ordinary) are absorbed except those which together appear pinkish-brown.

Again, all crystals of tourmaline in the direction of the vertical axis are opaque, since the ordinary ray, vibrating normal to the axis, is absorbed, while light-colored varieties, looked through laterally, are transparent, for the extraordinary ray, vibrating parallel to the axis, is not absorbed; the color differs in different varieties. Thus all uniaxial crystals may be *dichroic* or have two distinct axial colors.

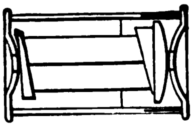
The absorption-colors are most satisfactorily investigated by examining a section cut parallel to the vertical (optic) axis under the microscope provided with a single polarizing nicol. The light that passes through the section is then that corresponding to vibrations coinciding with the known vibration-plane of the nicol, and as the section is rotated 90°, both the two axial colors are observed in succession. References to some important papers on this subject are given on p. 219.

An instrument called a *dichroscope*, contrived by Haidinger, is sometimes used for examining this property of crystals. An oblong rhombohedron of Iceland spar has a glass prism of 18° cemented to each extremity. It is placed in a metallic cylindrical case, as in the figure, having a convex lens at one end, and a square hole at the other. On looking through it, the square hole appears double; one image belongs to the ordinary and the other to the extraordinary ray. When a pleochroic crystal is examined with it by transmitted light, on revolving it the two squares, at intervals of 90° in the revolution, have different colors, corresponding to the vibration-planes of the ordinary and extraordinary ray in calcite. Since the two images are situated side by side, a very slight difference of color is perceptible.

531.



532.



366. Circular Polarization.—The subject of elliptically polarized light and circular polarization has already been briefly alluded to in Art. **323**. This phenomenon is most distinctly observed among minerals in the case of crystals belonging to the rhombohedral-trapezohedral group, that is, quartz and cinnabar.

It has been explained that a section of an ordinary uniaxial crystal cut normal to the vertical (optic) axis appears dark in parallel polarized light for every position between crossed nicols. If, however, a similar section of quartz, say 1 mm. in thickness, be examined under these conditions, it appears dark in monochromatic light only, and that not until the analyzer has been rotated so that its vibration-plane makes for sodium light an angle of 24° with that of the polarizer. In other words, this quartz section has rotated the plane of polarization (*i.e.*, the vibration-plane normal to it) some 24°, and here either to the right or to the left, looking in the direction of the light. The *amount* of this rotation increases with the thickness of the section, and as the wave-length of the light diminishes (for red this angle of rotation for a section of 1 mm. is about 19°, for blue 32°). The direction of the rotation is to the right or left, as defined above—according as the crystal is crystallographically right-handed or left-handed (p. 83).

If the same section of quartz (cut perpendicular to the axis) be viewed between crossed nicols in converging polarized light, it is found that the interference-figure differs from that of an ordinary uniaxial crystal. The central portion of the black cross has disappeared, and instead the space within the inner ring is brilliantly colored.* Furthermore, when the analyzing nicol is revolved, this color changes from blue to yellow to red, and it is found that in some cases this change is produced by revolving the nicol to the *right,* and in other cases to the *left;* the first is true with right-handed crystals, and the second with left-handed. If sections of a right-handed and left-handed crystal are placed together in the polariscope, the center of the interference-figure is occupied with a four-rayed spiral curve, called, from the discoverer, *Airy's spiral.* Twins of quartz crystals are not uncommon, consisting of the combination of right- and left-handed individuals (according to the Brazil law) which show these spirals of Airy. With cinnabar similar phenomena are observed. Twins of this species also not infrequently show Airy's spirals in the polariscope.

C. BIAXIAL CRYSTALS.

General Optical Relations.

367. Principal Refractive Indices.—All crystals of the third or anisometric class, that is, those of the orthorhombic, monoclinic, and triclinic systems, are optically *biaxial.* In the directions of the optic axes there is a single value only for the light velocity, but in other directions † a light-ray is separated into two rays propagated with different velocities; that is, it suffers double refraction.

The study of biaxial crystals shows that there are two directions within them at right angles to each other, corresponding to which, as vibration-axes, the refractive indices have respectively a *minimum* (α) and a *maximum* value (γ) for the given substance. Further, in a third direction at right angles to each of those just named, the refractive index has a certain intermediate value, related to the others by a simple mathematical law. These three rectangular directions, or ether-axes, are properly axes of vibration, and the three corresponding refractive indices determine the rate of this transverse vibration and hence the velocity of the light-ray which corresponds to each of them. The values of the velocities are respectively proportional to $\frac{1}{\alpha}, \frac{1}{\beta}, \frac{1}{\gamma}$.

The indices α, β, γ are called the *principal refractive indices* for the given substance. The mean refractive power is given by their arithmetical mean, viz., $\frac{\alpha + \beta + \gamma}{3}$. Further, the difference between the greatest and least index, $\gamma - \alpha$, measures the birefringence or *strength* of the double refraction.

368. Optical Structure of Biaxial Crystals.—It is found further that the optical structure of a biaxial crystal can be represented by an ellipsoid having as its axes the three lines mentioned in the preceding article which are at right angles to each other and proportional in length to the indices α, β, γ. This indeed would be inferred (following Fresnel) from the analogy of uniaxial crystals. The position of the axes named, or, in other words, the symmetry of this ellipsoid, is such as to correspond to the general crystallographic symmetry of the crystal. For example, to repeat the statement already made (Art. **348**), in the *orthorhombic* system the axes of this ellipsoid coincide in direction with the crystallographic axes. In the *monoclinic* system, one of them coincides with the axis of crystallographic symmetry ($\bar{b}$), the other two lie in the plane of symmetry, that is, in the plane of the crystallographic axes $\grave{a}$ and $\acute{c}$. In the *triclinic* system there is no necessary connection between the position of the ether-axes and the crystallographic axes.

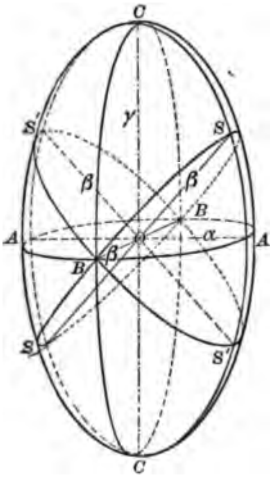
---

* Very thin sections of quartz, however, show (*e.g.*, with the microscope) the dark cross of an ordinary uniaxial crystal.

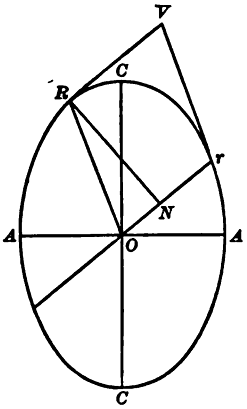
† On the distinction between the primary and the secondary optic axes, see Art. 371.

369. Indicatrix.—It may be shown, as is done by Fletcher, that the ellipsoid mentioned, whose axes represent in magnitude the three principal refractive indices, α, β, γ (where $\alpha < \beta < \gamma$), not only exhibits the character of the optical symmetry, but also serves to represent the direction, velocity and plane of polarization of a light-ray in any direction whatever, precisely analogous to the spheroid mentioned on p. 196. See Fig. 533 (from Groth), also Figs. 518, 519. That is, for the two rays having any *direction*, as *Or* in the plane of the axes *AA*, *CC* (Fig. 534), the velocities will be proportional to $\frac{1}{RN}$ and $\frac{1}{OB}\left(=\frac{1}{\beta}\right)$ respectively, and the planes of polarization will be perpendicular to these lines. From the equation of this index-ellipsoid, called by Fletcher the *indicatrix* (see Art. **355**), it is possible, as shown by the author named, to deduce by ordinary analytical methods the mathematical expression for the wave-surface, the position of the two sets of optic axes (later explained), etc.

533.



534.



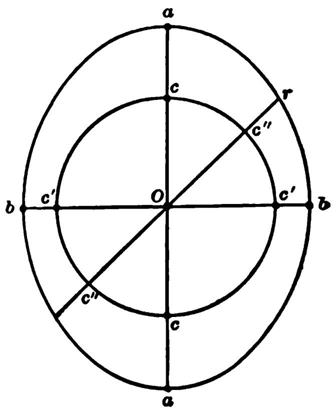
One important relation appears at once from a first study of this ellipsoid. Obviously for two definite positions of transverse planes passing through the center (*SS*, *S'S'*, Fig. 533), these positions depending upon the relative values of α and γ, the cross-sections will be *circles* each having a radius equal to the index β, intermediate in value between α and γ; similarly all sections parallel to these are also circles. Hence, light propagated in a direction normal to these planes, that is, by vibrations lying in them, will suffer no double refraction—and after the analogy of uniaxial crystals these directions are called *optic axes;* they are the *primary optic axes* mentioned in Art. **371**.

370. Wave-surface.—Following out the analogy of uniaxial crystals, Fresnel deduced the now generally accepted "wave-surface" for biaxial crystals. That it gives correctly the law of the varying refractive indices (that is, of varying light-velocity) in a biaxial crystal has been demonstrated by the agreement between the requirements of the theory and the results of experiment.

The form of the sections of this wave-surface with the three rectangular axial planes are easily deduced by very elementary considerations, though the full analytical development is most satisfactorily derived from the equation of the indicatrix as shown by Fletcher.

First consider the section of the wave-surface for the transverse plane of the axes *AB* (Fig. 533). Light passing in the direction of the axis *AA* will be separated into two rays; for one of these the line of transverse vibration will correspond to the axis *CC*, and hence its rate, or, in other words, the velocity of the ray itself, will be proportional to $\frac{1}{\gamma}$. For the second, the direction of transverse vibration will be that of the axis *BB*, and its rate, that is, the velocity of the ray itself, will be proportional to $\frac{1}{\beta}$. Let these values be represented in Fig. 535 by $Oc'\left(=\frac{1}{\gamma}\right)$ and $Ob\left(=\frac{1}{\beta}\right)$. Again, in the direction of the axis *BB*, there will be two rays whose vibration-directions are respectively parallel to the axes *AA* and *CC*, and their velocities in the direction of *BB* proportional to $\frac{1}{\alpha}$ and $\frac{1}{\gamma}$ respectively. Let these be represented by *Oa* and *Oc*. For some other direction in the same plane, there will be two rays, one of whose vibration-directions corresponds to *CC*, and its velocity to $\frac{1}{\gamma}$, represented in Fig. 533 by *Oc''*, while for the other there will be an intermediate vibration-direction and a velocity between $\frac{1}{\alpha}$ and $\frac{1}{\gamma}$, and it can be shown (after the analogy of uniaxial crystals and as proved by experiment) that this value is given by the line *Or* in the ellipse whose major and minor axes (*Oa* and *Ob*) are $\frac{1}{\alpha}$ and $\frac{1}{\gamma}$. Hence the circle *cc'* represents the section of the wave-surface for the rays in the given plane, whose vibration-direction corresponds to the axis *CC*, and the velocity to the constant value $\frac{1}{\gamma}$. While for other rays the vibration-directions change from *AA* to *BB*, and the velocity from $\frac{1}{\alpha}$ to $\frac{1}{\beta}$.

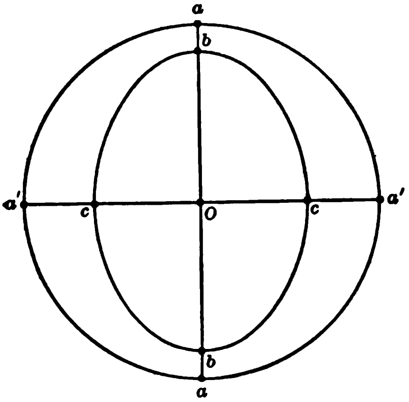
535.



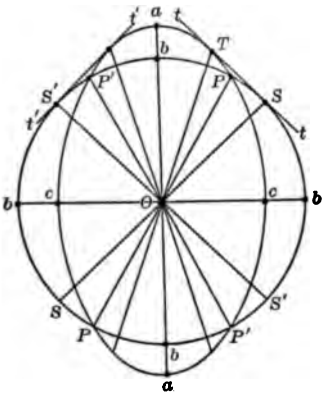
The ray propagated by vibrations in the direction of the axis *CC*, which has the constant velocity $\frac{1}{\gamma}$, that is, the ray whose wave-front in this cross-section is a circle, is called the *ordinary ray*, since on refraction it remains in the plane of incidence. The other ray, whose velocity varies with the direction from $\frac{1}{\alpha}$ to $\frac{1}{\beta}$, is called the *extraordinary ray*.

Again, take the plane of the axes *BC* (Fig. 533). Whether the direction of the light be that of *B* or of *C*, or any intermediate line in the same plane, there will be in each position one ray whose vibration-direction is that of the axis A, and whose velocity is hence expressed by $\frac{1}{\alpha}$; for it the section of the wave-surface will be a circle. For the other ray, if parallel to B, the vibration-direction will be that of the axis C, and its velocity is represented by $\frac{1}{\gamma}$. If it is parallel to C, its vibration-direction is that of B, and its velocity is given by $\frac{1}{\beta}$. As in the other case, intermediate values will be given by the ellipse having $\frac{1}{\beta}$ and $\frac{1}{\gamma}$ for its major and minor axes. The combined section of the wave-surface is shown in Fig. 536. Here also, the ray with the constant velocity $\frac{1}{\alpha}$ is called the ordinary ray; the other is the extraordinary ray.

536.

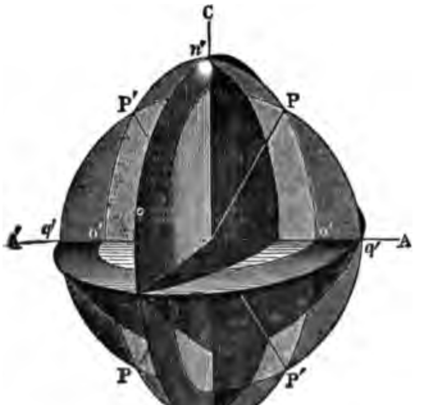


537.



For the third plane, that of the axes AC, one ray will always have as its vibration-direction that of the axis B, and its velocity will hence be expressed by $\frac{1}{\beta}$. For the other ray, if parallel to A, the vibration-direction is that of C, and the velocity is expressed by $\frac{1}{\gamma}$. If parallel to C, the vibration-direction is that of A and the velocity $\frac{1}{\alpha}$, and similarly for intermediate positions. The section of the wave-surface constructed from these values is given in Fig. 537. Here the circle $\left(\text{radius} = \frac{1}{\beta}\right)$ cuts the ellipse at the points PP, $P'P'$. The complete wave-surface, of which the three axial sections are given in Figs. 535, 536, and 537, can be constructed, but it is not easy to form a

538.

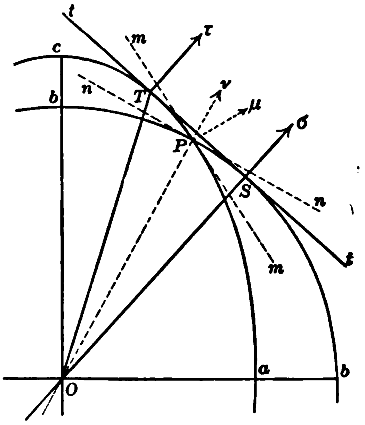


complete knowledge of the form without having a model in hand. Some idea of it may be gathered from Fig. 538.

371. Primary and Secondary Optic Axes.—It has already been briefly stated (Art. **367**) that there are two directions, namely, those normal to the circular cross-sections of the indicatrix (*SS*, *S'S'*, Fig. 533) in which the light is propagated by transverse vibrations of like rate $\left(\frac{1}{\beta}\right)$. Hence in these directions in a crystal there is no double refraction within the crystal; nor is there when the ray emerges. These two directions bear so close an analogy to the optic axes of a uniaxial crystal that they are also called *optic axes*, and the crystals here considered are hence named *biaxial*. In Fig. 537, these optic axes have the direction *SS*, *S'S'* normal to the tangent planes *tt*, *t't'*, and the direction of the external wave is given by the normal $S\sigma$ (Fig. 539).

Properly speaking the directions mentioned are those of the *primary optic axes*, for there are also two other somewhat analogous directions, *PP*, *P'P'*, of Fig. 537, called for sake of distinction the *secondary optic axes.* The properties of the latter directions are obvious from the following considerations.

539.



In the section of the wave-surface shown in Fig. 537 (also enlarged, in Fig. 539), corresponding to the axial plane *AC*, it is seen that the circle with radius *Ob* $\left(=\frac{1}{\beta}\right)$ intersects the ellipse whose major and minor axes are *Oa* $\left(=\frac{1}{\alpha}\right)$ and *Oc* $\left(=\frac{1}{\gamma}\right)$ in the four points *P*,*P*, *P'*,*P'*. Corresponding to these directions the velocity of propagation is obviously the same for both rays. Hence within the crystal these rays travel together without double refraction. Since, however, there is no common wave-front for these two rays (for the tangent for one ray is represented by *mm* and for the other by *nn*, Fig. 539) they do suffer double refraction on emerging; in fact, two external light-waves are formed whose directions are given by the normals $P\mu$ and $P\nu$. These directions, *PP*, *P'P'*, therefore have a relatively minor interest, and whenever, in the pages following, optic axes are spoken of, they are always the *primary* optic axes, that is, those having the directions *SS*, *S'S'* (Fig. 537), or *OS*, Fig. 539.* In practice, however, as remarked in the next article, the angular variation between the two sets of axes is usually very small, perhaps 1° or less.

372. Interior and Exterior Conical Refraction.—The tangent plane to the wave-surface drawn normal to the line *OS* through the point *S* (Fig. 539) may be shown to meet it in a small circle on whose circumference lie the points *S* and *T*. This circle is the base of the interior cone of rays *SOT*, whose remarkable properties will be briefly hinted at. If a section of a biaxial crystal be cut with its faces normal to *OS*, those parallel rays belonging to a cylinder having this circle as its base, incident upon it from without, will be propagated within as the cone *SOT*. Conversely, rays from within corresponding in position to the surface of this cone will emerge *parallel* and form a circular cylinder. This phenomenon is called *interior conical refraction*.

---

* Fletcher calls the primary axes *binormals*, the secondary axes *biradials*.

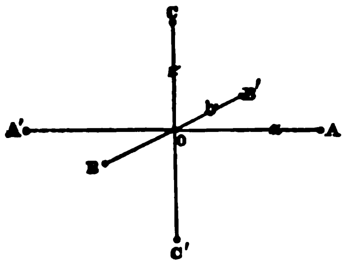
On the other hand, if a section be cut with its faces normal to *OP*, those rays having the direction of the surface of a cone formed by perpendiculars to *mm* and *nn* will be propagated within parallel to *OP*, and emerging on the other surface form without a similar cone on the other side. This phenomenon is called *exterior conical refraction.*

In the various figures given (535–539) the relations are much exaggerated for the sake of clearness; in practice the relatively small difference between the indices of refraction α and γ makes this cone of small angular size, rarely over 2°. For example, with sulphur, which has very strong double refraction ($\gamma - \alpha = 0·29$; compare the values given in Art. **359** and Art. **382**), the values of α, β, γ for yellow sodium light were measured by Schrauf as follows:

$$\alpha = 1·95047, \qquad \beta = 2·03832, \qquad \gamma = 2·24052.$$

373. Axes of Elasticity.—As intimated in Art. **368**, Fresnel appears to have deduced the wave-surface of biaxial crystals, as it is here called following him, by a generalization from that accepted for the more simple uniaxial crystals. The explanation of the observed phenomena, attempted by him, was based upon the assumption that the varying velocity of light shown by the varying values of the refractive indices depended upon the variable *elasticity* of the ether within the crystal. Since, as stated on p. 160, it seems better not to insist upon this hypothesis and since, further, it is possible to describe all the phenomena without attempting to explain the properties of the ether upon which the ultimate values of the pulses depend which manifest themselves as light-waves, all mention of elasticity has been thus far avoided. These "axes of elasticity" are of great convenience in describing the optical properties of crystals, and it is hence necessary to make frequent use of them. They are uniformly represented by the letters $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, where $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$ as shown in Fig. 540, and where further it is true that $\mathfrak{a} : \mathfrak{b} : \mathfrak{c} = \frac{1}{\alpha} : \frac{1}{\beta} : \frac{1}{\gamma}$, α, β, γ being the three principal refractive indices ($\alpha < \beta < \gamma$). The three axes as given in Fig. 540 then have the direction of the three ellipsoidal axes (Fig. 533); the maximum value of the elasticity, $\mathfrak{a}$, corresponds to the minimum value of the observed refractive index α, and this in turn corresponds to the maximum velocity of a ray propagated perpendicular to the plane of the axes $\mathfrak{a}$ and $\mathfrak{b}$ by vibrations having a direction parallel to this axis $\mathfrak{a}$; similarly for the axes $\mathfrak{b}$ and $\mathfrak{c}$.

540.



Whenever in this work the axes $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, which may be simply called the *ether-axes*, are spoken of in describing the optical characters of crystals, it is to be understood that they have the directions indicated, corresponding respectively, as just explained, to the ellipsoidal axes; moreover, their relative magnitude is expressed as follows: $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$.

374. Bisectrices, or Mean-lines.—As shown in Art. **371**, the optic axes always lie in the plane of the axes α, γ of the indicatrix (that is, of the ether-axes $\mathfrak{a}$ and $\mathfrak{c}$); this is called the optic axial plane (or briefly, *ax. pl.*). The value of the optic axial angle is known when the values of the refractive indices, α, β, γ, are given, as stated in the next article. That axis (cf. Fig. 539, also Figs. 541, 542) which bisects the acute angle of the optic axes is called the *acute bisectrix*, or *first mean-line*, and that bisecting the obtuse angle is the *obtuse bisectrix*, or *second mean-line.*

The acute bisectrix is often represented by Bx_a, the obtuse bisectrix by Bx_o.

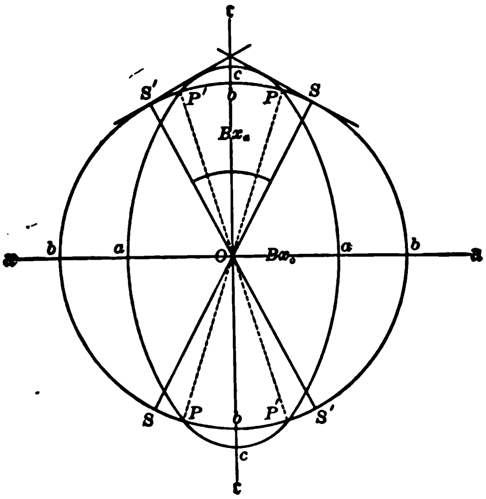
If the word *bisectrix* is used alone without special qualification it is always to be understood as referring to the acute bisectrix.

375. Relation of the Axial Angle to the Refractive Indices.—If in a given case the values of α, β, and γ are known, the value of the interior optic axial angle ($2V$) can be calculated from them by the following formulas:

$$\cos^2 V = \frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{\alpha^2} - \frac{1}{\gamma^2}} \quad \text{or} \quad \tan^2 V = \frac{\frac{1}{\alpha^2} - \frac{1}{\beta^2}}{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}.$$

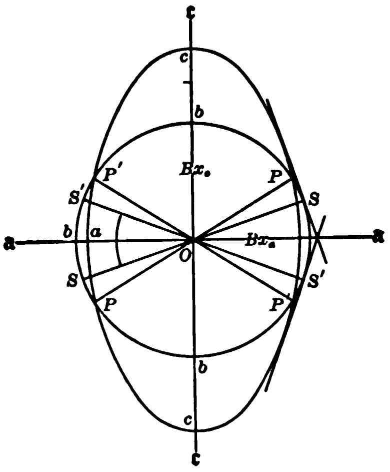
376. Positive and Negative Crystals.—Biaxial crystals are distinguished as *optically positive* (+) or *negative* (−) after a manner analogous to the usage with uniaxial crystals. Referring to Fig. 533 of the ellipsoid, and also to Fig. 539, it will be obvious at once that for certain relative values of the indices, α, β, γ, the interior optic axial angle must be 90°. In other words, in this case the planes of the optic axes will be equally inclined to the two planes of the ether-axes. Such a case, however, is rare in practice, and when it occurs it is true for light of a certain color * (wave-length) only, and not for others.

541.



Positive Crystal, $Bx_a = \mathfrak{c}$.

542.



Negative Crystal, $Bx_a = \mathfrak{a}$.

---

* For danburite $2V = 89°\ 14'$ for green (thallium) and $90°\ 14'$ for blue ($CuSO_4$).

Roughly expressed,* the optic axes will lie nearer to c than to a—that is, c will be the bisectrix—when the value of the intermediate index, β, is nearer that of α than to that of γ. Such a crystal, for which $Bx_a = c$, is called *optically positive.* It is obvious (cf. Fig. 541) that in this case, as the angle diminishes and becomes nearly equal to zero, the form of the ellipsoid then approaches that of the prolate spheroid of the positive uniaxial crystal as its limit (Fig. 521, p. 195); this shows the appropriateness of the + sign here used.

On the other hand, the optic axes will lie nearer to a than to c—that is, a will be the bisectrix—if the value of the mean index β is nearer† to that of γ than to that of α. Such a crystal, for which $Bx_a = a$, is called *optically negative.* It is seen that in this case (Fig. 542) the smaller the angle the more the ellipsoid approaches the oblate spheroid of the negative uniaxial crystal (Fig. 520, p. 195).

The following are a few examples of positive and negative biaxial crystals:

Positive (+).	Negative (−).
Sulphur.	Aragonite.
Enstatite.	Hypersthene.
Topaz.	Muscovite.
Barite.	Orthoclase.
Chrysolite.	Epidote.
Albite.	Axinite.

377. Dispersion of the Bisectrices.—In certain cases the ether-axes of Fig. 533 may have different positions in the crystal for different colors; that is, for different wave-lengths. This is true of the two axes which lie in the plane of symmetry of a monoclinic crystal, and of all the three axes in a triclinic crystal. This results in a phenomenon which is often called the *dispersion of the bisectrices,* and which, if pronounced, is always manifest in the axial interference-figures, as explained beyond.

378. Dispersion of the Optic Axes.—Further, since the three refractive indices may have different values for the different colors, and as the angle of the optic axes is determined by these three values (Art. **375**), the axial angle may also vary in a corresponding manner.

This variation in the value of the axial angle for light of different wave-lengths is called the *dispersion of the optic axes,* and the two extreme cases are distinguished by writing $\rho > v$ when the angle for the red rays (ρ) is greater than for the blue (violet, v), and $\rho < v$ when the reverse is true. These cases are illustrated later.

Examination of Biaxial Crystals in Polarized Light.

379. Sections in Parallel Polarized Light. Extinction-angle.—A section of a biaxial crystal appears dark between crossed nicols when its vibration-planes coincide with the vibration-planes of the nicols. In any other position of the

---

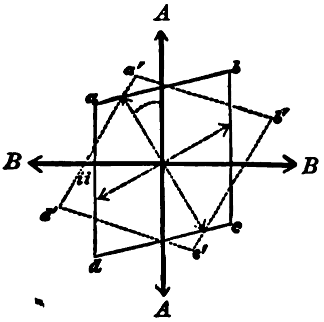
* $\tan V = 45°$ and $2V = 90$ for a value of β given by the equation

$$\frac{1}{\alpha^2} - \frac{1}{\beta^2} = \frac{1}{\beta^2} - \frac{1}{\gamma^2}.$$

† To compare Figs. 542 and 520, the horizontal axis of the former should be placed in a vertical position; that is, the axis AA of Fig. 520 corresponds to c of Fig. 542.

section it appears light and may show the usual bright interference-color. Hence the use of the polariscope, or polarization-microscope, by the method of extinction, gives a quick means of determining the position of these vibration-planes in a given case.

543.



For example, in Fig. 543, repeated from p. 177, let the two larger rectangular arrows represent the vibration-directions for the two nicols, and between the two prisms suppose a section of a biaxial crystal, *abcd*, to be placed so that one edge of a known crystallographic plane coincides with the direction of one of these lines. The field of the microscope, dark before, since the prisms were crossed, is no longer so, and becomes dark again, as explained, only when the crystal is revolved so that *its* vibration-directions (the smaller dotted arrows) coincide with those of the nicols, as is indicated by the maximum extinction of the light. The crystal has then the position *a'b'c'd'*. The angle (indicated in the figure) which it has been necessary to revolve the plate to obtain the effect described, is the angle which one of the vibration-directions in the given plate makes with the given crystallographic edge *ad*; it is often called the *extinction-angle*.

When the vibration-planes of a crystal-section coincide in direction with the planes of its crystallographic axes, the extinction is said to be *parallel*; if not, it is called *oblique* or *inclined*. On the practical determination of the extinction-directions see Arts. **380** and **389**.

380. Determination of the Extinction-directions with the Microscope.—In the use of the microscope, in cases to which the method of the stauroscope is not applicable, instead of depending upon the somewhat uncertain estimate of the point of maximum light-extinction, a convenient way is to employ a plate of quartz, which for a certain position of the analyzer gives the field a tint of color (a purplish pink), to slight changes in which the eye is very sensitive. When the section is revolved on the stage till it has precisely the same tint as the surrounding field, its vibration-planes are those of the cross-hairs in the eyepiece (supposing the lower nicol has the normal position), and from the graduation of the stage their position in the section can be at once determined.

Instead of the quartz, a plate of selenite (Art. **364**) of such a thickness as to give the red of the first order is often employed, the nicols being crossed. When this plate is inserted as usual, the crystal-section can have the same color only on condition that its vibration-directions coincide with those of the nicols; hence their crystallographic orientation in the section is readily determined and with considerable accuracy.

A still more delicate method involves the use of the *Bertrand ocular*. This has four sectors of quartz cut $\perp \dot{c}$: two of these, diagonally opposite, are from a right-handed, the other pair from a left-handed crystal. When the diameters in which the sectors meet coincide with the vibration-directions of the two crossed nicols, the two pairs of quadrants have precisely the same color; any change of position, however, of the upper nicol causes them to assume tints complementary to each other.

Assuming now the nicols to be crossed and in the normal position, if a section of a doubly refracting mineral be introduced on the stage of the microscope, the quadrants in general take unlike tints and are brought to the same color as before only when by the revolution of the stage the vibration-directions of the section are made to correspond precisely to those of the crossed nicols, that is, of the diameters of the ocular. The adjustment can be made in this case with great accuracy.

381. Relation of the Vibration-directions to the Ether-axes.—In the most general case, for any section whatever, the relation between the vibration-planes and the ether-axes is highly complex.* A common special case is where the section is parallel to one of the ether-axes; this then fixes one vibration-plane, and the other will obviously be at right angles to it. A still more special case is that of a section parallel to the plane of two of the ether-axes; these axes then at once fix the directions of light-vibration and conversely; or, in other words, these directions being determined by observation, the position of the axes in the crystal section is known from them.

The practical application of the above relations depends upon the crystallographic orientation of the ether-axes, and is spoken of later under the different systems.

382. Color of a Section in Parallel Polarized Light.—The interference-color of the section under examination depends, as before explained, upon its thickness and upon the birefringence; the latter varies with the orientation of the section, but is a maximum (equal to $\gamma - \alpha$) if the section is cut parallel to the axes $\mathfrak{a}$ and $\mathfrak{c}$, that is, parallel to the plane of the optic axes. In any case for a given thickness the interference-color will depend upon the difference between the refractive powers of the two vibration-directions. For sake of illustration, the following table is added (from Rosenbusch) giving the thickness of section for a few biaxial crystals which yield red of the first order, with also their maximum birefringence ($\gamma - \alpha$).

	Birefringence ($\gamma - \alpha$).	Thickness in millimeters.
Brookite	0·158	0·00349
Muscovite	0·042	0·01312
Epidote	0·037	0·01490
Augite	0·022	0·02505
Gypsum	0·010	0·05510
Orthoclase	0·008	0·06887
Zoisite	0·006	0·09183

Further, it may be noted that with a section of epidote ‖b (010), while a thickness of about 0·015 mm. gives red of the first order, one of 0·028 gives red of the second order, and of 0·042 red of the third order.

383. Determination of the Birefringence with the Microscope.—The value of the maximum birefringence ($\gamma - \alpha$) is obviously given at once when the refractive indices are known. It can be approximately estimated for a section of proper orientation and of measured thickness by the comparison of the interference-color with the table referred to in Art. **320**, p. 178. This is on the assumption that the thickness is such as to yield a tint of readily recognized position in the interference-scale. To which order a given interference-color belongs can be readily determined by the compensation method involving the use of the quartz-wedge or the mica-wedge of Fedorow (Art. **384**).

---

* The variation in directions of extinction with change of the orientation of the section under examination is chiefly interesting in the microscopic study of rock-sections. It is minutely discussed in the Minéraux des Roches of M. Lévy and Lacroix. The same subject has also been exhaustively treated in the case of the plagioclase feldspars by M. Lévy in a work in two parts entitled "Étude sur la détermination des Feldspaths dans les plaques minces" (Paris, 1894, 1896). Cf. also Fedorow, Zs. Kryst., **22**, 248, 1893; **27**, 337, 1896; **29**, 604, 1898; also Viola, Min. petr. Mitth., **15**, 481, 1895.

More accurate measurements of the birefringence can be made by other methods, as with the quartz-comparator of M. Lévy.*

384. Determination of the Relative Refractive Power.—The relative refractive power of the two vibration-directions in a thin section is readily determined with the microscope (in parallel polarized light) by the method of compensation. This is applicable to any section, whatever its orientation and whether uniaxial or biaxial. Practically, however, it is chiefly employed when the section is parallel to the plane of two of the ether-axes; it then serves to determine the relative magnitude of these axes. If the position of either bisectrix in the section is known, it also serves to determine whether the crystal is optically positive or negative. In practice a mica-plate or selenite-plate may be used with very thin sections; or with thicker ones a quartz-wedge or the excellent mica-wedge of Fedorow.† The section under examination must be placed so that its vibration-directions make an angle of 45° with those of the crossed nicols; the $\frac{1}{4}$-undulation mica or selenite-plate is then inserted. The change in the interference-colors is noted, and again after the stage has been revolved 90°. In the case where the effect of the compensating plate is to *raise* the interference-color in the scale the retardation of the section is *added* to that of the plate; for this position the plate and section are then alike in optical character. In the case of a fall of color the plate diminishes the retardation due to the section; obviously for this position they are opposed in optical character.

For thicker sections placed in position as before with vibration-directions inclined 45° to those of the crossed nicols, the quartz-wedge or mica-wedge is employed. This is advanced across the field until a thickness is reached which serves to make the given section, previously colored, dark, that is, to bring it sensibly to extinction. The optical character of the plate and section are now opposed, and in fact just balanced against each other. By observing the position of the section the relative value of the refractive power is given.

A crystal-section is said to have *positive elongation* if its direction of extension approximately coincides with the ether-axis $\mathfrak{c}$; if with $\mathfrak{a}$ the elongation is *negative*. The same terms are also used in general, according to the relative refractive power of the two directions.

385. Determination of the Refractive Indices.—The values of the three refractive indices, α, β, γ, for biaxial crystals, may be determined from three prisms cut with their refracting edges parallel respectively to the three axes, $\mathfrak{a}$, $\mathfrak{b}$, and $\mathfrak{c}$, corresponding to the indices α, β, γ, respectively. See Art. **304**.

It is possible, however, to obtain the values of α, β, and γ by the use of *two* prisms; in this case one of the prisms must be so made that its vertical edge is parallel to one axis, while the line bisecting its refracting angle at this edge is parallel to a second. In the case of such a prism the angle of minimum deviation is obtained for both rays, that having its vibrations parallel to the prism-edge, and that vibrating at right angles to this, that is, parallel to the line bisecting the prismatic angle.

Of the three indices the mean index, β, is one which it is most important to determine, since by means of it, in accordance with the formulas in Art. **389**, the true value of the axial angle can be calculated from its apparent value in air. The prism to give the value of β should obviously have its refracting edge parallel to the axis **b**, that is, at right angles to the plane of the optic axes.

---

* See M. Lévy, Bull. Soc. Min., **6**, 143, 1883; also Lévy-Lacroix, Min. Roches, p. 54 *et seq.*; Rosenbusch, Mikr. Phys., p. 163 *et seq.*

† This consists of strips of $\frac{1}{4}$-undulation mica, overlapping step-like and all placed with their axial planes (*i.e.*, the axis $\mathfrak{c}$) in a common line coinciding with the direction of elongation. Inserted between crossed nicols, the axis $\mathfrak{c}$ making an angle of 45° with their vibration-planes, it gives a series of *areas* of interference-colors whose position in the scale is at once obvious (Art. **320**). See Fedorow, Zs. Kryst., **25**, 349, 1895.

The other methods* alluded to on pp. 180, 181 may also be applied here. For the method by total reflection the sections should be cut normal to the acute bisectrix. This will give by actual observation the values of α and γ, and if $2E$, the apparent axial angle in air, is known, then β, the mean index, can be calculated.

386. Interference-figure for a Section Normal to an Optic Axis.—A section cut perpendicular to either optic axis will show, in *converging* polarized light, a system of concentric rings analogous to the concentric circles of uniaxial crystals, Fig. 526, but more or less elliptical in shape. There is, moreover, no black cross, but a single black line, which revolves as the section is turned around on the stage.†

387. Interference-figures for Sections Normal to a Bisectrix.—If a section of a biaxial crystal, cut perpendicularly to the acute bisectrix, is viewed in the conoscope (p. 181), two types of characteristic interference-figures are observed, according to the position of the optic axial plane relative to the vibration-planes of the crossed nicols.

First, suppose that the plane of the axes coincides with the vibration-plane of one of the crossed nicols; an unsymmetrical black cross is then observed, and also a series of elliptical curves, surrounding the two centers and, finally uniting, forming a series of lemniscates. If monochromatic light is employed, the rings are alternately light and dark; in white light each ring shows the successive colors of the spectrum. If one of the nicol prisms be revolved, the dark hyperbolic brushes gradually become white, and the colors of the rings take the complementary tints after a revolution of 90°.

The smaller the axial angle the nearer together are the oval centers and the more the interference-figure resembles the simple cross of a uniaxial crystal. On the other hand, when the axial angle is large the hyperbolas are far apart, and may even be so far apart as to be invisible in the field of the polariscope. When this is not the case a micrometer scale in the polariscope, Fig. 514, p. 182, allows of an approximate measurement of the axial angle, the value of each division of the scale being known.

Again, suppose that the plane of the axes makes an angle of 45° with the vibration-planes of the crossed nicols; two black hyperbolas are then noted, marking the position of the axes; further, there is a system of curves similar to those described before.

Both of these figures are well exhibited on the plate forming the frontispiece (Figs. 3*a* and 3*b*). The one gradually changes into the other as the crystal-section is revolved in the horizontal plane, the nicols remaining stationary.

A section of a biaxial crystal cut perpendicular to the obtuse bisectrix exhibits the same figures under the same conditions in polarized light, when the angle is not too large. This is, however, generally the case, and in consequence the axes suffer *total reflection* (Art. **303**) on the inner surface of the section and no axial figures are visible. This is sometimes the case also with a section cut normal to the acute bisectrix, when the angle is large. (See, also,

---

* Becke has given a simple method for determining approximately the *relative* refractive power of two adjacent minerals (*e.g.*, quartz and a certain kind of plagioclase) in thin sections. Ber. Ak. Wien, **102** (1), July, 1893. See also Viola, Min. petr. Mitth., **16**, 150, 1896.

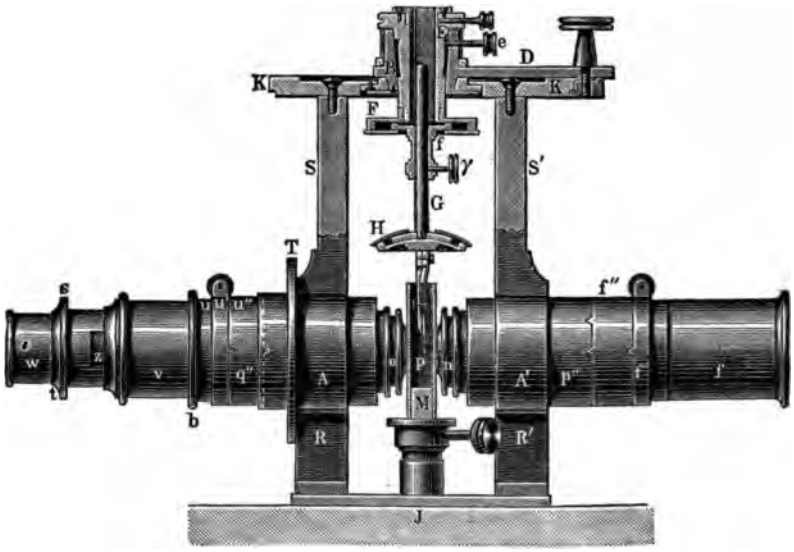
† On the special phenomena of sections of biaxial crystals cut normal to an optic axis, in parallel and converging polarized light, see Kalkowsky, Zs. Kryst., **9**, 486, 1884.

Art. 389.) The peculiarities in the interference-figures due to the dispersion of the optic axes and that due to the dispersion of the bisectrices, or both together, are alluded to later.

388. The explanation of the biaxial interference-figures—most simply understood for the first case mentioned—is analogous to that for the analogous phenomenon of the uniaxial crystals (Art. 360). The arms of the black cross mark the directions in which the light-rays, which are sensibly normal to the section, are extinguished, since the vibration-planes of the nicols coincide with those of the section. The dark ellipses and lemniscate curves seen in monochromatic light are due to the interference of the two rays produced by the double refraction of the section and referred back to a common vibration-plane by the polarizer. This interference takes place when the retardation of one ray relatively to the other is equal to half a wave-length, $\frac{1}{2}\lambda$, or to $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc. The intermediate light-spaces correspond to a similar retardation of a whole wave-length, λ, or 2λ, 3λ, etc. When ordinary light is employed there is complete extinction only in the direction of the vibration-planes of the nicols, and the curves become colored rings showing the prismatic colors. The number of colored rings noted in the field of view increases, and their distance from the axial centers and from each other grows less as the thickness of the plate is increased, and also as the strength of the double refraction is greater. If the plate is very thick, only the black cross may be distinctly visible.

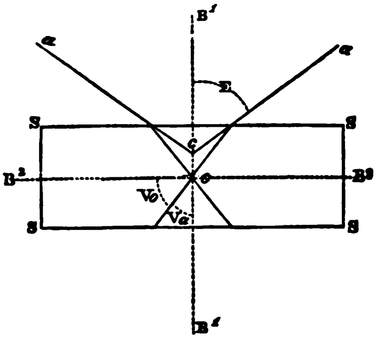
389. **Measurement of the Axial Angle.**—The determination of the angle made by the optic axes is ordinarily accomplished by use of the instrument shown in Fig. 544. The section of the crystal, cut at right angles to the bisectrix, is held in the pincers at *p*, with the plane of the axes *horizontal*, and making an angle of 45° with the vibration-plane of the nicols. There is a cross-wire in the focus of the eyepiece, and as the pincers holding the section are turned by the screw at the top (here omitted) one of the axes, that is, one

544.



black hyperbola, is brought in coincidence with the vertical cross-wire, and then, by a further revolution, the second. The angle which the section has been turned from one axis to the second, as read off at the vernier on the graduated circle above, is the *apparent* angle for the axes of the given crystal as seen in the air ($aca = 2E$, Fig. 545). It is only the *apparent* angle, for, on passing from the section of the crystal to the air, the true axial angle is more or less increased, according to the refractive power of the given crystal. The relation between the real interior angle and the measured angle is given below.

545.



If the axial angle is so large that the axes suffer total reflection, oil* or some other liquid with higher refractive power is made use of, into which the axes pass when no longer visible in the air. In the instrument described a small receptacle holding the oil is brought between the tubes, as seen in the figure, and the pincers holding the section are immersed in this and the angle measured as before.

In the majority of cases it is only the acute axial angle that it is practicable to measure; but sometimes, especially when oil (or other liquid) is made use of, the obtuse angle can also be determined from a second section normal to the obtuse bisectrix.

If E = the apparent semi-acute axial angle in air (Fig. 545),
H_a = " " " " " in oil,
H_o = " " semi-obtuse angle in oil,
V_a = the real (or interior) semi-acute angle,
V_o = " " " " semi-obtuse angle,
n = refractive index for the oil or other medium,
β = the mean refractive index for the given crystallized substance,

the following simple relations connect the various quantities mentioned:

$$\sin E = n \sin H_a; \quad \sin V_a = \frac{n}{\beta} \sin H_a; \quad \sin V_o = \frac{n}{\beta} \sin H_o.$$

These formulas give the true interior angle ($2V$) from the measured apparent angle in air ($2E$) or in oil ($2H$) when the mean refractive index (β) is known.

Instead of the oil, carbon disulphide with a refractive index of 1·6442 for $Na (n_y)$ may be employed; or the solution of mercuric iodide in potassium iodide, whose refractive index (Na) is 1·7176. The axial angle measured in the latter is usually represented by $2K$. Methyl iodide may also be used, since its refractive index is also high; for it n_y = 1·7466. The axial angle in this case is called $2M$.

Another modified form of axial instrument (the Adams-Schneider) incloses the section in a sphere of glass which can be turned at the proper angle; for this the axial angle is $2G$. The advantages of this instrument consist in the fact that the field of view is very large, and at the same time it allows of placing the section in any desired position relatively to the axis. Moreover, the angle measured is the apparent angle for the glass of which the lenses are made, so that the axes are visible in cases where this would not be the case, because of total reflection, either in air or in oil.

---

* [illegible] which has been decolorized by exposure to the light is commonly [illegible]active index is about 1·46.

390. **Axial Angle Measured with the Microscope.**—The microscope, with eyepiece removed and condensing lens (or lenses) added above the lower nicol, often serves to show (with suitable high-power objective) the axial interference-figures in very thin sections with only the limitations belonging to the instrument (see p. 199). Bertrand* has shown that by the addition of a simple piece of apparatus the axial angle can be measured with fair accuracy. Further, a very convenient apparatus for this object has been devised by Klein. Again, by the careful measurement of the linear distance between the two hyperbolas the axial angle can be calculated as shown by Mallard.†

391. Determination of the Positive or Negative Character of Biaxial Crystals.—The question of the positive or negative character of a biaxial crystal is determined from the values of the indices of refraction, where these can be obtained. If c, the ether-axis corresponding to the index γ, is the acute bisectrix, the crystal is optically *positive;* if a, the ether-axis corresponding to α, is the acute bisectrix, the crystal is optically *negative*; as explained in Art. 376 and illustrated by Figs. 541, 542, this relation follows from the values of the refractive indices.

There are, however, more simple methods of determining the character by experiment. The quarter-undulation mica plate may be employed just as with uniaxial crystals, but its use is not very satisfactory excepting when the axial divergence is quite small. In this case it can be used to advantage, the plane of the axes of the crystal investigated being made to coincide with the vibration-plane of one of the nicols. With the microscope the selenite plate may be employed after a manner similar to that explained in Art. **364**.

392. The more general method is the employment of a thin, wedge-shaped piece of quartz; this is so cut that one surface coincides with the direction of the vertical axis, and the other makes an angle of 4° to 6° with it. By this means a wedge of varying thickness is obtained. The section to be examined, cut normal to the acute bisectrix, is brought between the crossed nicols of the polariscope (Fig. 513), and with its axial plane making an angle of 45° with the polarization-plane of the nicol prisms; that is, so that the black hyperbolas are visible. The quartz-wedge is now introduced slowly between the section examined and the analyzer, *first,* in a direction at right angles to the axial plane, that is, to the line joining the hyperbolas, of the plate investigated; and *second,* parallel to the axial plane, that is, in the direction of the line joining the hyperbolas. In one direction or the other it will be seen, when the proper thickness of the quartz-wedge is reached, that the central rings appear to increase in diameter, at the same time advancing from the center to the extremities.

The effect, in other words, is that which would have been produced by the *thinning* of the given section. If the phenomenon is observed in the first case when the axis of the quartz is parallel to the axial plane, that is, to the obtuse bisectrix, it shows that this bisectrix must have an opposite sign to the quartz, that is, the obtuse bisectrix is negative, and the acute bisectrix *positive.* If the mentioned change in the interference-figures takes place when the axis of the quartz is at right angles to the axial plane, then obviously the opposite must be true and the acute bisectrix is *negative.* This method of investigation can be applied even in cases where the axial angle is too large to appear in the air.

---

* Bertrand, Bull. Soc. Min., 3, 97, 1880; see, also, Nachet, ibid., 10, 186, 1887; Klein, Ber. Ak. Berlin, 91, 1895. Also references in p. 199.

† Mallard, Bull. Soc. Min., 5, 77, 1882; this last method is explained by Rosenbusch, Mikr. Phys., 194, 1892.

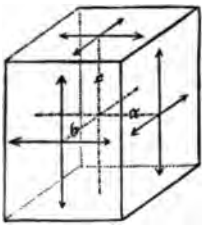
The same effects may be obtained by bringing an ordinary quartz section of greater or less thickness, cut normal to the axis, between the analyzer and the crystal examined, and then inclining it, first in the direction of the axial plane, and again at right angles to it.

The method of determining the optical character in thin sections in *parallel* polarized light is mentioned in Art. 384.

393. Absorption Phenomena of Biaxial Crystals. Pleochroism.—Biaxial crystals, corresponding to the fact that they have three principal refractive indices (α, β, γ) may show different degrees or kinds of absorption in different directions, usually assumed as those of the ether-axes, viz., $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$. The degree of absorption is designated as $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$ or $\mathfrak{a} > \mathfrak{b} = \mathfrak{c}$, etc. Further, according to the kind of selective absorption, the crystal may be dichroic or trichroic, or better, in general, *pleochroic;*[*] in this case the colors corresponding to the vibrations parallel to the ether-axes are usually given. It has been shown, however, that the axes of absorption do not in all cases coincide with the ether-axes.

In order to investigate the absorptive properties of a biaxial crystal, sections must be obtained which are parallel to the several ether-axes, cf. Fig. 546. In an orthorhombic crystal the faces are those of the three pinacoids; in a monoclinic crystal one side coincides with the clinopinacoid, the others are to be determined for each species. The light transmitted by this solid, or by the corresponding sections, is examined by means of a single nicol prism. Suppose, first, that the light transmitted (Fig. 546) in the direction of the vertical axis is to be examined. When the shorter diagonal of the nicol coincides with the direction of the axis $\mathfrak{b}$, the color observed belongs to that ray with vibrations parallel to this direction; when it coincides with the axis $\mathfrak{a}$, the color for the ray with vibrations parallel to $\mathfrak{a}$ is observed. In the same way the nicol separates the different colored rays vibrating parallel to $\mathfrak{c}$ and $\mathfrak{a}$ respectively, when the light passes through in the direction of $\mathfrak{b}$.

546.



So also finally when the section is looked through in the direction of the axis $\mathfrak{a}$, the colors for the rays vibrating parallel to $\mathfrak{b}$ and $\mathfrak{c}$, respectively, are obtained. It is evident that the examination in two of the directions named will give the three possible colors. All of these observations are readily made with the microscope provided with one nicol.

For epidote, according to Klein, the colors for the three axial directions are:

1. Vibrations parallel to $\mathfrak{b}$, brown (absorbed).
" " " $\mathfrak{a}$, yellow.

2. Vibrations parallel to $\mathfrak{c}$, green.
" " " $\mathfrak{a}$, yellow.

3. Vibrations parallel to $\mathfrak{c}$, green.
" " " $\mathfrak{b}$, brown (absorbed).

The colors observed by the eye alone are the resultants of the double set of vibrations, in which the stronger color predominates; thus, in the above example, the plane normal to $\mathfrak{c}$ is brown, to $\mathfrak{b}$ yellowish-green, to $\mathfrak{a}$ green. In any other direction in the crystal the apparent color is the result of a mixture of those corresponding to the three directions of vibrations in different proportions.

When a section (normal to an optic axis) of a crystal characterized by a high degree of color-absorption is examined by the eye alone (or with the microscope) in strongly converging light, it often shows the so-called *epoptic figures*,* or *polarization-brushes*, somewhat resembling the ordinary axial interference-figures. This is true of andalusite, epidote, iolite, also tourmaline, etc. A cleavage section of epidote ‖*c* (001) held close to the eye and looked through to a bright sky shows the polarization-brushes, here brown on a green ground.

---

[*] Early observations were made by Haidinger, see literature below.

It is also to be noted that certain strongly absorbing crystals (*e.g.*, biotite) often show spots where the color is particularly deep; such areas are sometimes called *pleochroic halos*.

LITERATURE.

Haidinger. Pogg. Ann., **61**, 295, 1844; **65**, 1, 1845; Ber. Ak. Wien, **13**, 3, 306, 1854.
Senarmont. C. R., **38**, 101, 1854; or Pogg. Ann., **9**, 491, 1854.
Tschermak. Ber. Ak. Wien, **60** (1), 5, 1869.
Lang. Improved dichroscope. Ibid., **82** (2), 174, 1881.
Klein. Epidote. Jb. Min., 113, 1872.
Bertin. "Houppes," etc. Ann. Ch. Phys., **15**, 396, 1878, and Zs. Kryst., **3**, 449, 1879. Also Bertrand, Bull. Soc. Min., **2**, 67, 1879; Mallard, ibid., p. 72.
Laspeyres. Piedmontite. Zs. Kryst., **4**, 444, 1880.
Pulfrich. Zs. Kryst., **6**, 142, 158, 1881.
Mallard Bull. Soc. Min., **2**, 72, 1879; **6**, 45, 1883.
Voigt. Jb. Min., **1**, 119, 1885; Wied. Ann., **31**, 233, 1887.
Ramsay. Epidote. Zs. Kryst., **13**, 97. 1887.
Liebisch. Nachr. Ges. Göttingen, No. 8, 202, 1888.
Ehlers. Jb. Min., Beil.-Bd., **11**, 259, 1897.

Special Optical Characters of Orthorhombic Crystals.

394. Position of the Ether-axes.—In the ORTHORHOMBIC SYSTEM, in accordance with the symmetry of the crystallization, the three axes of the indicatrix, that is, the ether-axes a, b, c, *coincide* with the three crystallographic axes, and the three unlike crystallographic planes of symmetry correspond to the planes of symmetry of the ellipsoid. Further than this, there is no immediate relation between the two sets of axes in respect to magnitude, for the reason that, as has been stated, the choice of the crystallographic axes is arbitrary so far as relative length and position are concerned, and hence made, in most cases, without reference to the optical character.

Sections of an orthorhombic crystal parallel to a pinacoid plane (*a*, *b*, or *c*) appear dark between crossed nicols, when the axial directions coincide with the vibration-planes of the nicols. In intermediate positions a section will appear light (or colored if of the proper thickness). Hence such a section when revolved on the microscope will appear dark four times.

The same will be true of a section cut in the prismatic zone (‖ $\dot{c}$, the vertical axis) or in the plane parallel either to the axis $\bar{b}$ or $\breve{a}$.

395. Determination of the Plane of the Optic Axes.—The plane of the *optic axes*, that is, of the axes a and c, corresponding to the indices α and γ, must be parallel to one of the three pinacoids. In order to determine in which plane the axes lie, it is necessary to examine sections parallel to these directions. One of these will in all ordinary cases show, in converging polarized light, the interference-figure peculiar to biaxial crystals. It is evident also that two of the sections named determine the character of the third, so that the plane of the optic axes and the position of the acute bisectrix can be in practice generally told from them.

The position of the optic axial plane is briefly indicated according to the pinacoid to which it is parallel: as, ax. plane ‖ *a* (100), etc. Further, the position of the acute bisectrix is described according to the pinacoid to which it is normal, as $Bx_a \perp c$, etc.

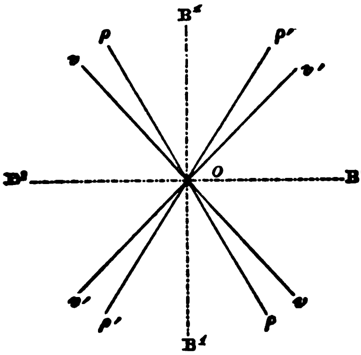
---

* These figures are called *houppes* by the French and *Polarisationsbüschel* by the German mineralogists. Such crystals are said to be *idiophanous*.

396. Dispersion of the Axes.—From the section showing the axial figures, that is, normal to the acute bisectrix, the axial angle can be measured in the manner which has been described (Art. **389**). If it is practicable to determine also the obtuse axial angle from a second section normal to the obtuse bisectrix, the true axial angle ($2V$) and also the mean refractive index (β) can then be calculated.

There is further to be determined the dispersion of the axes (see Art. **378**). Whether the axial angle for red rays is greater or less than for blue ($\rho > v$, or $\rho < v$) can be often seen immediately from the axial interference-figure in the colored plate (frontispiece); it is obviously true, from Fig. 3*a*, as also Fig. 3*b*, that the angle for the blue rays is greater than that for the red ($\rho < v$), and so in general. This same point is also accurately determined, of course, by the measured angle for the two colors.

547.



In all cases the same line will be the bisectrix of the axial angle for both blue and red rays, so that the position of the respective optic axes is symmetrical with reference to each bisectrix. In Fig. 547, the dispersion of the axes is illustrated, where $\rho < v$; it is shown also that the lines B^1B^1 and B^2B^2 bisect the angles of both red ($\rho O \rho'$) and blue ($v O v'$) rays. It also needs no further explanation that for a certain relation of the refractive indices of the different colors, the acute bisectrix of the axial angle for red rays may be the obtuse bisectrix for the angle for blue rays. This is true, for example, in the case of the species danburite, as already noted (p. 209).

397. Refractive Indices, etc.—The determination of the refractive indices and the character (+ or −) of the acute bisectrix is made for orthorhombic crystals in the same way as for all biaxial crystals. It is merely to be mentioned that, since the ether-axes always coincide with the crystallographic axes, it sometimes happens that crystals, without artificial preparation, furnish, in their prismatic or dome series, prisms whose edges are parallel to these axes, and consequently at once suitable for the determination of the indices of refraction. This is often true, for example, with topaz. It must be noted, however, that if the refractive angle is too large, the refracted ray will not emerge (see Art. **303**), the limit being when the angle of the prism is equal to twice the critical angle.

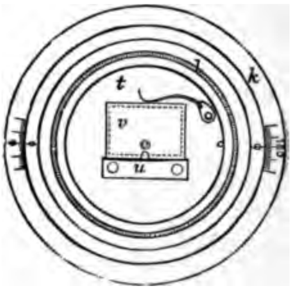
Special Optical Characters of Monoclinic Crystals.

398. Position of the Ether-axes and Optic Axial Plane.—In crystals belonging to the MONOCLINIC SYSTEM one of the ether-axes always coincides with the orthodiagonal axis *b*, and the other two lie in the plane of symmetry at right angles to this axis. Here obviously three cases are possible, according to which two of the axes, 𝔞, 𝔟, or 𝔠, lie in the plane of symmetry.

Corresponding to these three positions of the ether-axes, there may occur three kinds of dispersion of these axes, or *dispersion of the bisectrices* (Art. **377**). This dispersion arises from the fact that, while the position of one axis is fixed, the position of the other two may be different for the different colors (wave-lengths), so that the bisectrices of the different colors may not coincide.

399. Stauroscope.—The position of the two axes in the plane ot symmetry may be determined by use of the microscope as described in Art. **380**. A more accurate method, applicable in certain cases, involves the principle of the stauroscope, an instrument first devised by von Kobell (1855[*]), and since then much improved. In its present form it is simply the orthoscope of Fig. 515 with a composition plate of calcite inserted at *m* in the upper tube. This gives a peculiar interference-figure the form of which is altered if a doubly refracting section is placed on the stage below, unless its vibration-planes coincide with those of the crossed nicols. The adjustment which restores the normal figure can be made with great precision. To accomplish this, it is essential that the direction of the known edge of the crystal should be exactly parallel to the vibration-direction of one of the nicols. This condition, in the case of small crystals especially, is hard to fulfill, and to accomplish it most satisfactorily the holder shown in Fig. 548 is made use of. A plate of glass, *v*, held in its present position by a spring, has one edge polished, that which adjoins *u*, and the direction of this is made to coincide exactly with the line joining the opposite zero points of the graduation. The crystal section is attached to this plate over the hole seen in *v*, and with a plane of known crystallographic position, either *a*, *c* or a face in that zone (or a corresponding edge), coinciding with the direction of the polished edge of the plate. Whether this coincidence is exact can be tested by the reflecting goniometer.

548.



After the adjustment of the section on the plate *v*, the latter is inserted in its place, the whole plate placed in position (Fig. 515), and the nicols so adjusted that the vibration-plane of one coincides with the line 0° to 180°. The angle of revolution of the circular plate, *l*, is obtained from the graduated scale on *k*.

It is not always easy to make the adjustment of the nicols alluded to, but the error arising when the vibration-plane of the nicol does not coincide with the line 0° to 180° is easily eliminated. This is accomplished by removing the plate *v*, and, without disturbing the crystal section, restoring it to its place in an inverted position. The measured angle, if before too great, will now be as much too small, and the arithmetical mean of the two measurements will be the true angle. (Cf. Groth, l. c.)

400. Position of the Plane of the Optic Axes.—The investigation of a section of a monoclinic crystal parallel to the plane of symmetry determines the position of the two ether-axes lying in this plane, but it does not fix the relative position of the axes 𝔞 and 𝔠, that is, the plane of the optic axes. To solve the latter point, sections normal to each of the three axes must be examined in converging polarized light, and one of them will show the characteristic interference-figure. The section parallel to the plane of symmetry is first to be examined, and if it does not show the axes even in oil, one or both of the other sections spoken of must be employed.

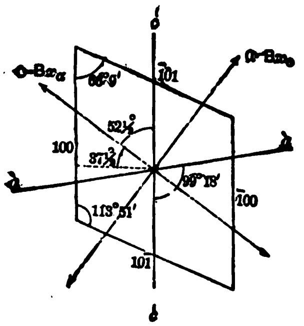
---

[*] Pogg. Ann., **95**, 320, 1855; also Brezina, ibid., **128**, 448, 1866; **130**, 141, 1869; Groth, ibid., **144**, 84, 1871; Calderon, Zs Kryst., **2**, 68, 1877.

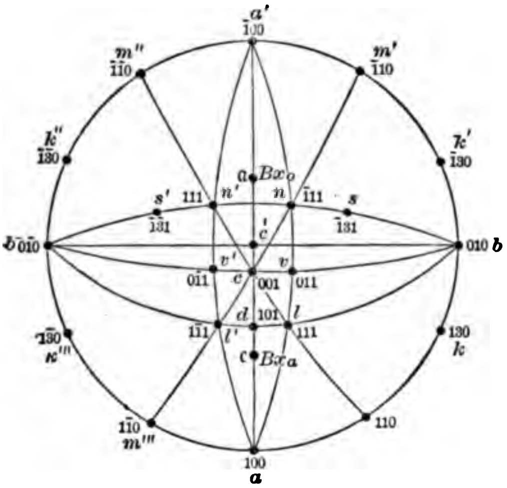
The position of the optic axial plane is described as ∥ *b* or ⊥ *b* according as it is parallel or normal to the plane of symmetry, that is, to the face *b* (010). In the former case, the position of the bisectrices may be defined according to the angle which the acute bisectrix (Bx_a) makes either with the normal to the face *a* (100) or that of *c* (001) or with the vertical axis *ċ*. The last method is particularly convenient since the direction of the vertical crystallographic axis, *ċ*, is that marked by the prismatic zone (*e.g.*, in a section by cleavage lines), and still more since the extremity of *ċ* is the middle point of the sphere of projection (Fig. 550) and the angle is either + (in front, toward 100) or − (behind, toward $\bar{1}00$).

For example, gypsum is optically positive, hence the axis, c, is the acute bisectrix, Bx_a. Further (Figs. 549, 550), the position of Bx_a is defined by the angle $Bx_a \wedge \dot{c} = +52\frac{1}{2}°$. But since the axial angle *β*, or *ac* (001 ∧ 100), = 80° 42′, it is also true that the normal

549.

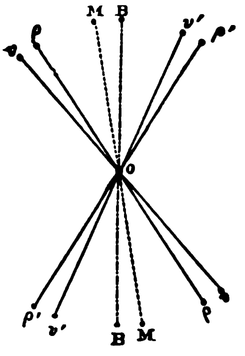


550.



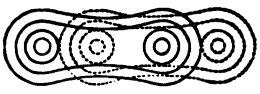
angles between c or a and the planes *c*, *a* are as follows: c*c* = + 43° 12′, a*c* = + 37° 30′, and c*a* = − 46° 48′. The positions of the bisectrices are shown in the section parallel to *b* (010) of Fig. 549, and also in the sphere of projection, Fig. 550.

551.



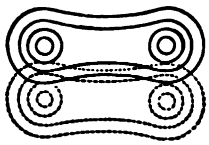
401. Dispersion of the Bisectrices.—1. INCLINED DISPERSION.—In this first case the plane of the optic axes is parallel to the face *b* (010); in other words, the two bisectrices (the axes a and c) lie in the plane of symmetry, and the mean axis b coincides with the orthodiagonal axis. The optic axes may here suffer a dispersion in this plane of symmetry, and, as already stated, they then do not lie symmetrically with reference to the acute bisectrix. This is illustrated in Fig. 551, where *MM* is the bisectrix for the angle *vOv′*, and *BB* for the angle *ρOρ′*. This kind of dispersion was called by Des Cloizeaux *inclined* (dispersion inclinée). The position of the two axial planes is further illustrated by Fig. 552 (from Schrauf), and corresponding to this the axial interference-figure, when the dispersion is considerable, shows a distribution of colors illustrated by Figs. 4*a* and 4*b* of the plate (frontispiece), which should be compared with the normal figures (Figs. 3*a* and 3*b*), where there is no dispersion of the bisectrices.

552.



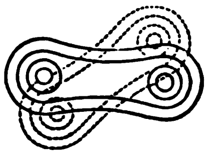
1. Inclined.
Ax. pl. ∥ *b* (010).

553.



2. Horizontal.
Ax. pl. $\perp b$; $Bx_o \perp b$.

554.



3. Crossed.
Ax. pl. $\perp b$; $Bx_a \perp b$.

2. Horizontal Dispersion. In the second case the acute bisectrix and b lie in the plane of symmetry, and the optic axial plane is hence normal to it. In other words, the plane of the optic axes for all the colors lies parallel to the orthodiagonal axis, but these planes may have different inclinations to the vertical axis. This was called *horizontal* dispersion by Des Cloizeaux.

The relative positions of the axial planes is illustrated by Fig. 553, and the resulting interference-figure is shown in Fig. 5 of the plate.

3. Crossed Dispersion. In the third case the obtuse bisectrix and b lie in the plane of symmetry, that is, the plane of the optic axes is normal to this plane and the acute bisectrix coincides with the orthodiagonal axis *b*. This was called *crossed* dispersion by Des Cloizeaux (dispersion tournante or croisée). The relative positions of the axial planes is illustrated by Fig. 554 and the corresponding interference-figure is shown in Fig. 6 of the plate.

402. Axial Angle, Dispersion, etc.—The method of measuring the axial angle has been already explained, and if this is determined for the different colors it will determine the dispersion of the axes $\rho \lessgtr v$.

The dispersion of the bisectrices has been shown to be in general indicated by the character of interference-figures; its amount, where considerable, may be determined by making the stauroscopic measurements for different colors.

The remaining points to be investigated, the refractive indices, the + or − character of the crystal, etc., need no further explanation beyond that which has been already given.

Special Optical Characters of Triclinic Crystals.

403. The crystals of the triclinic system are characterized by the absence of a plane of crystallographic symmetry, the position and inclination of the axes being thus arbitrary. It follows from this that there is no necessary connection between them and the rectangular ether-axes. More than one of the three kinds of dispersion mentioned in Art. **401** may occur in a single crystal, and the interference-figures will indicate the existence of both.

The practical investigation of triclinic crystals optically involves considerable difficulty; in general a series of successive trials are required to determine the position of the axes. When these are found, the axial sections can be prepared and the axial angle determined, and the other points settled as with other biaxial crystals. Cf. Fig. 341, p. 109, of chalcanthite, where *S* represents approximately the position of Bx_a, or in other words is the pole or normal to the plane at right angles to the acute bisectrix. On the general relation between the extinction-directions, ether-axes and optic axes, see the authors referred to on p. 212.

---

404. Effect of Heat upon Optical Characters.—The general effects of heat upon crystals as regards expansion, etc., are spoken of later. It is convenient, however, to consider here, briefly, the changes produced by this means in the special optical characters. It is assumed that no alteration of the chemical composition takes place and no abnormal change in molecular structure. The essential facts are as follows:

(1) *Isotropic* crystals remain isotropic at all temperatures. Crystals, however, which like sodium chlorate ($NaClO_3$ of Group 5, p. 51) show circular polarization, may have their rotatory power altered; in this substance it is increased by rise of temperature.

(2) *Uniaxial* crystals similarly remain uniaxial with rise or fall of temperature; the only change noted is a variation in the relative values of ω and ϵ, that is, in the strength of the double refraction. This increases, for example, with calcite and grows weaker with beryl and quartz. It is, further, interesting to note that the rotatory power of quartz increases with rise of temperature, but the relation for all parts of the spectrum remains sensibly the same.

(3) With *Biaxial crystals*, the effect of change of temperature varies with the system to which they belong.

The axial angle of biaxial crystals may be measured at any required temperature by the use of a metal air-bath. This is placed at P (Fig. 544), and extends beyond the instrument on either side, so as to allow of its being heated with gas-burners; a thermometer inserted in the bath makes it possible to regulate the temperature as may be desired. This bath has two openings, closed with glass plates, corresponding to the two tubes carrying the lenses, and the crystal-section, held as usual in the pincers, is seen through these glass windows. Suitable accessories to the refractometer also allow of the measurement of the refractive indices at different temperatures.

In the case of *orthorhombic* crystals, the position of the three rectangular ether-axes cannot alter, since they must always coincide with the crystallographic axes. The values of the refractive indices, however, may change, and hence with them also the optic axial angle; indeed a change of axial plane or of the optical character is thus possible.

For example, Des Cloizeaux gives the following values for barite: $2E_r = 63° 5'$ at 12° C., 69° 49′ at 95·5°, 74° 42′ at 195·8°. Further, Arzruni obtained the following measuments of the refractive indices of the same species for the D line:

	α	β	γ	$2E$	$2V$
At 20°	1·63609	1·63712	1·64795	64° 1′	37° 28′
" 50°	1·63575	1·63678	1·64726		38° 43′
" 100°	1·63512	1·63612	1·64643	68° 51′	40° 15′
" 200°	1·63344	1·63474	1·64426	77° 16′ (204°)	44° 18′

With *monoclinic* crystals, one ether-axis must coincide at all temperatures with the axis of symmetry, but the position of the other two in the plane of symmetry may alter, and this with the possible change in the value of the refractive indices may cause a variation in the degree (or kind) of dispersion as well as in the axial angle.

With *triclinic* crystals, both the positions of the ether-axes and the values of the refractive indices may change. The observed optical characters may therefore vary widely.

A striking example of the change of optical characters with change of temperature is furnished by gypsum, as investigated by Des Cloizeaux. At ordinary temperatures, the dispersion is inclined, the axial plane is ‖b and $2E_r = 95°$. As the temperature rises this angle diminishes; thus at 47°, $2E_r = 76°$; at 95°, $2E_r = 39°$; and at 116°, $2E_r = 0$. At this last temperature the axes for blue rays have already separated in a plane $\perp b$; at 120° the axes for red rays also separate in this plane ($\perp b$) and the dispersion becomes *horizontal.* The motion toward the center of one red axis is more rapid than that of the other, namely between 20° and 95°, 33° 55′ and 22° 38′, respectively; thus Bx_r moves 5° 38′.

Another interesting case is that of glauberite. Its optical characters under normal conditions are described as follows: Optically —. Ax. pl. $\perp b$, $Bx_{a.r.} \wedge \dot{c} = -31° 3'$, $Bx_{a.y} = -30° 46'$, $Bx_{a.bl} \wedge \dot{c} = -30° 10'$. The optical character (—) and the position of the axes of elasticity remain sensibly constant between 0° and 100°. The ax. pl., however, at first $\perp b$ with horizontal dispersion and $v < \rho$ becomes on rise of temperature ‖b with inclined dispersion and $v > \rho$. The axial angle accordingly diminishes to 0° at a temperature depending upon the wave-length and then increases in the new plane. In white light, therefore, the interference-figures are abnormal and change with rise in temperature. Axial angles, Laspeyres:

	red (Li)	yellow (Na)	green (Tl)	blue
At 5° 2E =	16° 6′	14° 8′	11° 42′	8° 51′
22° " =	13° 30′	11° 8′	8° 14′	0° (at 18°)
36° " =	11° 1′	8° 9′	0°	8° 42′
46° " =	8° 40′	0°	7° 8′	11° 8′
58° " =	0°	7° 14′	10° 32′	13° 2′
85° " =	10° 47′	13° 14′	15° 15′	17° 7′

Des Cloizeaux found that the feldspars, when heated up to a certain point, suffer a change in the position of the axes, and if the heat becomes greater and is long continued they do not return again to their original position, but remain altered.

In addition to the typical cases referred to, it is to be noted that when elevation of temperature is connected with change of chemical composition wide changes in optical characters are possible. This is illustrated by the zeolites and related species, where the effect of loss of water has been particularly investigated.

Further, with some crystals, heat serves to bring about a change of molecular structure and with that a total change of optical characters. For example, the greenish-yellow (artificial) orthorhombic crystals of antimony iodide (SbI_3) on heating (to about 114°) change to red uniaxial hexagonal crystals. Note also the remarks made later in regard to the effect of heat upon leucite and boracite (Art. 411).

405. Some Peculiarities in Axial Interference-figures.*—In the case of uniaxial crystals, the characteristic interference-figure varies but little from one species to another, such variation as is observed being usually due to the thickness of the section and the birefringence. In some cases, however, peculiarities are noted. For example, the interference-figure of apophyllite is somewhat peculiar, since its birefringence is very weak, and it may be optically positive for one part of the spectrum and negative for the other.

In the case of biaxial crystals, peculiarities are more common. The following are some typical examples:

Brookite is optically + and the acute bisectrix is always normal to a (100). While, however, the axial plane is ‖c for red and yellow, with $2E_r = 55°$, $2E_y = 30°$, it is commonly ‖b for green and blue, with $2E_{gr} = 34°$. Hence a section ‖a in the conoscope shows a figure somewhat resembling that of a uniaxial crystal but with four sets of hyperbolic bands.

Titanite also gives a peculiar interference-figure with colored hyperbolas because of the high color-dispersion, $\rho > v$; thus Des Cloizeaux gives $2E_r = 55°$ to 56°, $2E_r = 34°$; the dispersion of the bisectrices is, however, very small.

The most striking cases of peculiar axial figures are afforded by twin crystals (Art. 407).

406. Relation of Optical Properties to Chemical Composition.—The effect of varying chemical composition upon the optical characters has been minutely studied in the case of many series of isomorphous salts, and with important results.* It is, indeed, only a part of the general subject of the relation between crystalline form and molecular structure on the one hand and chemical composition on the other, one part of which has been discussed in Art. 302. It was shown there that the refractive index can often be approximately calculated from the chemical composition.

---

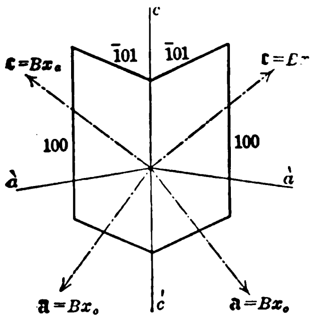
* Variations in the axial figures embraced under the head of optical anomalies are spoken of later (Art. 411).

Among minerals, the most important examples of the relation between composition and optical characters are afforded by the triclinic feldspars of the albite-anorthite series. Here, as explained in detail in the descriptive part of this work, the relation is so close that the composition of any intermediate member of this isomorphous group can be predicted from the position of its ether-axes, or more simply from the vibration-directions on the fundamental cleavage-directions, |c (001) and |b (010).

The effect of varying amounts of iron protoxide (FeO) is illustrated in the case of the monoclinic pyroxenes, where, for example, the angle $Bx_a \wedge \acute{c}$ is 36° in diopside (2·9 p. c. FeO) and 48° in hedenbergite (26 p. c. FeO). This is also shown in the closely related orthorhombic species of the same group, enstatite, $MgSiO_3$ with little iron, and hypersthene, $(Mg,Fe)SiO_3$ with iron to nearly 30 p. c. With both of these species the axial plane is parallel to b (010), but the former is optically + ($Bx_a = \mathfrak{c}$) and the dispersion $\rho < v$; the latter is optically − ($Bx_a = \mathfrak{a}$) and dispersion $\rho > v$. In other words, the optic axial angle increases rapidly with the FeO percentage, being about 90° for FeO = 10 p. c. In the case of the chrysolites, the epidotes, the species triphylite and lithiophilite, and others, analogous relations have been made out.

407. Optical Properties of Twin Crystals.—The examination of sections of twin crystals of any other than the isometric system in polarized light serves to establish the compound character at once and also to show the relative orientation of the several parts. This is most distinct in the case of contact-twins, but is also well shown with penetration-twins, though here the parts are usually not separated by a sharp line.

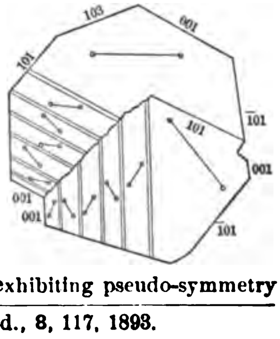
555.



Thus the examination of a section parallel to b (010) of a twin crystal of gypsum, of the type of Fig. 555, makes it easy not only to establish the fact of the twinning but also to fix the relative positions of the ether-axes in the two parts. The measurement can in such cases be made between the extinction-directions in the two halves, instead of between one of these and some definite crystallographic line, as the vertical axis.

The polysynthetic twinning of certain species, as the triclinic feldspars, appears with great distinctness in polarized light. For example, in the case of a section of albite, parallel to the basal cleavage, the alternate bands extinguish together and assume the same tint when the quartz section is inserted. Hence the angle between these directions is easily measured, and this is obviously double the extinction-angle made with the edge b/c. A basal section of microcline in the same way shows its compound twinning according to both the albite and pericline laws, the characteristic grating structure being clearly revealed in polarized light. Fig. 556 of a section of chondrodite (from Des Cloizeaux) shows how the compound structure is shown by optical examination; the position of the axial plane is indicated in the case of the successive polysynthetic lamellæ. The complex penetration-twins of right- and left-handed crystals of quartz (see the description of that species) also have their character strikingly revealed in polarized light.

556.

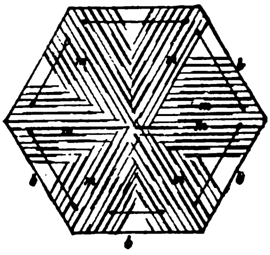


Still again, the true structure of complex multiple twins, exhibiting pseudo-symmetry in their external form, can only be fully made out in this way. This is illustrated by Fig. 557, a basal section of an apparent hexagonal pyramid of witherite (cf. Fig. 400, p. 128). The analogous six-sided pyramid of bromlite (Fig. 558) has a still more complex structure, as shown in Fig. 559. Fig. 560 shows a simple crystal of stilbite; Fig. 561 is the common type of twin-crystal, and Fig. 562 illustrates how the complex structure (∥ b 010) is revealed in polarized light. Other illustrations are given in Art. 411. It will be understood that the axial interference-figures of twin crystals, where the parts are superposed, often show many peculiarities; the Airy spirals of quartz (p. 203) will serve as an illustration.

---

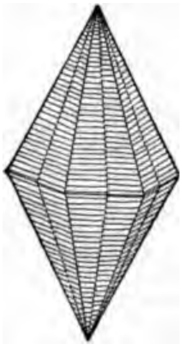
* See a recent paper by Pockels, Jb. Min., Beil.-Bd., 8, 117, 1893.

557.

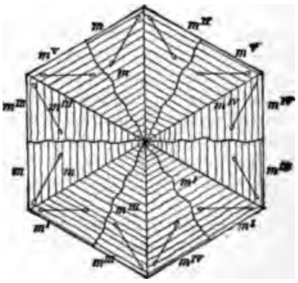


Witherite.

558.

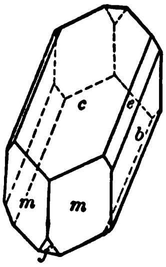


559.

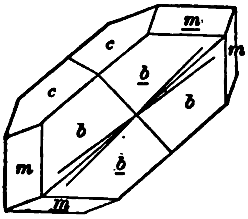


Bromlite (Des Cloizeaux).

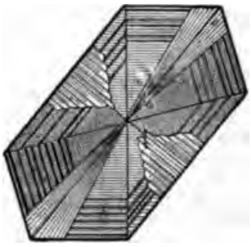
560.



561.



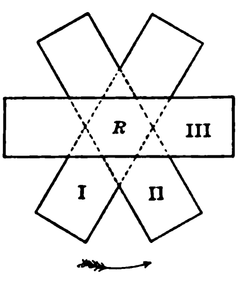
562.



Stilbite (Lasaulx).

408. A particularly interesting case, related to the subject discussed in the preceding article, is that of the special properties of superposed cleavage-sections of mica, as developed by Reusch.* If three or more of these, say of rectangular form, be superposed and so placed that the lines of the axial planes make equal angles of 60° (45°, etc.) with each other the effect is that polarized light which has passed through the center suffers circular polarization, with a rotation to right or left according to the way in which the sections are built up. The interference-figure resembles that of a section of quartz cut normal to the axis. This is illustrated in Fig. 563.

563.



If the sections are numerous and very thin the imitation of the phenomena of quartz is closer. As shown by

---

* Reusch, Pogg. Ann., 138, 628, 1869; Sohncke, ibid., Erg.-Bd., 8, 16, 1876, and Theorie der Krystallstruktur, 1879.

Sohncke and others, these facts throw much light upon the ultimate molecular structure of a crystallized medium showing circular polarization. Further, it is easy from this to understand how it is possible to have in sections of certain crystals (*e.g.*, of clinochlore) portions which are biaxial and others that are uniaxial, the latter being due to an intimate twinning after this method of biaxial portions.

409. Optical Properties of Crystalline Aggregates.—The special optical phenomena of the different kinds of crystalline aggregates described on pp. 142, 143, and the extent to which their optical characters can be determined, depend upon the distinctness in the development of the individuals and their relative orientation. The case of ordinary granular, fibrous, or columnar aggregates needs no special discussion. Where, however, the doubly refracting grains are extremely small, the microscope may hardly serve to do more than to show the *aggregate polarization* present.

A case of special interest is that of spherulites, that is, aggregates spherical in form and radiated or concentric in structure; such aggregates occur with calcite, various chlorites, feldspars, etc. If they are formed of a doubly refracting crystalline mineral, or of an amorphous substance which has birefringent characters due to internal tension, they commonly exhibit a dark cross in the microscope between crossed nicols; further, this cross, as the section is revolved on the stage, though actually stationary, seems to rotate backward.*

A distinct and more special case is that of spherical aggregates of a mineral optically uniaxial (or biaxial with a small angle). Sections of these (not central) in parallel polarized light show more or less distinctly the interference-figure of a uniaxial crystal.† The objective must be focussed on a point a little removed from the section itself, say on the surface of the sphere of which it is a part. In such cases the + or − character of the double refraction can be determined as usual.

410. Change of Optical Character Induced by Pressure.—As the difference between the optical phenomena exhibited by an isometric crystal on the one hand and a uniaxial or biaxial crystal on the other is referred to a difference in molecular structure modifying the properties of the ether, it would be inferred that if an amorphous substance were subjected to conditions tending to develop an analogous difference in its molecular structure it would also show doubly refracting properties.

This is found to be the case. Glass which has been suddenly cooled from a state of fusion, and which is therefore characterized by strong internal tension, usually shows marked double refraction. Further, glass plates subjected to great mechanical pressure in one direction show in polarized light more or less distinct interference-curves. Gelatine sections, also, under pressure exhibit like phenomena. Even the strain in a glass block developed under the influence of unlike charges of electricity of great difference of potential on its opposite sides is sufficient to make it doubly refracting.

In an analogous manner, as shown by Klein, Bücking, and others,‡ the double refraction of a crystal may be changed by the application of mechanical force. Klein found that pressure exerted normal to the vertical axis of a section of a tetragonal or hexagonal crystal which has been cut ⊥ ć, changes the uniaxial interference-figure into a biaxial, and with substances optically positive, the plane of the optic axes was parallel, and with negative substances normal, to the direction of pressure.

The quartz crystals in rocks, which have been subjected to great pressure, are often found to be in an abnormal state of tension, showing an undulatory extinction in polarized light.

411. Optical Anomalies.—Since the early investigations of Brewster, Herschel, and others (1815 *et seq.*) it has been recognized that many crystals exhibit optical phenomena which are not in harmony with the apparent symmetry of their external form. Crystals of many isometric species, as analcite, alum, boracite, garnet, etc., often show more or less pronounced double refraction, and sometimes they are distinctly uniaxial or biaxial. A section examined in parallel polarized light may show more or less sharply defined doubly refracting areas, or parallel bands or lamellæ with varying extinction. Occasionally, as noted by Klein in the case of garnet, while most crystals are normally isotropic, others show optical characters which seem to be determined by the external bounding faces and edges; thus, a dodecahedron may appear to be made up of twelve rhombic pyramids (biaxial) whose apices are at the center; a hexoctahedron similarly may seem to be made up of forty-eight triangular pyramids, etc.

---

* Cf. Rosenbusch, Mikr. Phys., 68 *et seq.*, 1892.

† Bertrand, C. R., **94**, 542, 1882; Mallard, Bull. Soc. Min., **4**, 67, 1881.

‡ This subject has been discussed by various authors, among whom (in recent years) are the following: Klocke, Jb. Min., **2**, 249, 1881; Bücking, Zs. Kryst., **7**, 555, 1883; Brauns, Jb. Min., **1**, 232, 1886; Klein, Ber. Ak. Berlin, 724, 1890; Pockels, Wied. Ann., **37**, 144, etc., 1889; **39**, 440, 1890; Jb. Min., Beil.-Bd., **8**, 217, 1893. See also literature on p. 231.

Similarly, crystals of many common tetragonal or hexagonal species, as vesuvianite, zircon, beryl, apatite, corundum, chabazite, etc., give interference-figures resembling those of biaxial crystals. Also, analogous contradictions between form and optical characters are noted with crystals of orthorhombic and monoclinic species, *e.g.*, topaz, natrolite, orthoclase, etc. All cases such as those mentioned are embraced under the common term of *optical anomalies.*

This subject has been minutely studied by many investigators in recent years (see literature), and important additions have been made to it both on the practical and the theoretical side. The result is that, though doubtful cases still remain, many of the typical ones have found a satisfactory explanation. No single theory, however, can be universally applied.

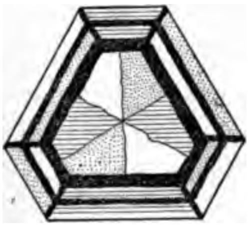
The chief question involved has been whether the anomalies are to be considered as secondary and non-essential, or whether they belong to the inherent molecular structure of the crystals in question. On the one hand, it has been urged that internal tension suffices (Art. **410**) to call out double refraction in an isotropic substance or to give a uniaxial crystal the typical optical structure of a biaxial crystal. On the other hand, it is equally clear that twinning often produces pseudo-symmetry in external form, and at the same time conceals or changes the optical characters. From the simplest case, as that of aragonite (Fig. 397), we pass to more complex cases, as witherite (Figs. 400, 401, and 557), bromlite (Figs. 558, 559), phillipsite (Figs. 362, 422–424), which last is sometimes pseudo-isometric in form, though optical study shows the monoclinic character of the individuals.* Reasoning from the analogy of these last cases, Mallard was led (1876) to the theory that the optical anomalies could in most cases be explained by the assumption of a similar but still more intimate grouping of molecules which themselves without this would unite to form crystals of a lower grade of symmetry than that which their complex twinned crystals actually simulate.

In regard to the two points of view mentioned, it seems probable that internal tension (due to pressure, sudden cooling, or rapidity of growth, etc.) can be safely appealed to to explain the anomalous optical character of many species, as diamond, halite, beryl, quartz, etc. Again, it has been fully proved that the later growth of isomorphous layers of varying composition may produce optical anomalies, probably here also to be referred to tension. Alum is a striking example. The peculiarities of this species were early investigated by Biot and made by him the basis of his theory of "lamellar polarization," but the present explanation is doubtless the true one. Fig. 564 (from Brauns) shows the appearance in polarized light of a section ‖ *o* (111) from a crystal in which the successive layers have different composition. Further, according to Brauns the optical peculiarities of many other species may be referred to this same cause. He includes here, particularly, those cases (as with some garnets) in which the optical characters seem to depend upon the external form, as noted above. Here belongs also apophyllite, a section of which (from Golden, Colo., by Klein) is shown in Fig. 565. The section has been cut ‖ *c* (001) through the center of the crystal and is represented as it appears in parallel polarized light.

---

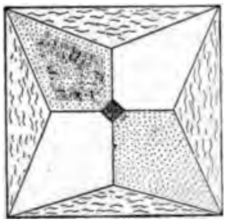
* Crystals showing pseudo-symmetry of highly complex type are called *mimetic* crystals by Tschermak.

564.



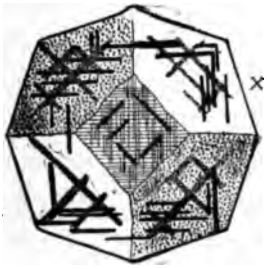
Alum, ‖ 111.

565.



Apophyllite, ‖ 001.

566.



Leucite, ‖ 100.

Another quite distinct but most important class is that including species such as boracite and leucite, which are *dimorphous;* that is, those species which at a certain elevation of temperature (300° for boracite and 500° to 600° for leucite) become strictly isotropic. Under ordinary conditions, these species are anisotropic, but the fact stated makes it probable that originally their crystalline form and optical characters were in harmony. The relations for leucite deserve to be more minutely stated.

Leucite usually shows very feeble double refraction: $\omega = 1{\cdot}508$, $\epsilon = 1{\cdot}509$. This anomalous double refraction, early noted (Brewster, Biot), was variously explained. In 1873, Rath, on the basis of careful measurements, referred the seemingly isometric crystals to the tetragonal system, the trapezohedral face 112 being taken as 111, and 211, 121 as 421, 241, respectively; also 101, 011 as 201, 021. Later Weisbach (1880), on the same ground, made them orthorhombic; Mallard, however, referred them (1876), chiefly on optical grounds, to the monoclinic system, and Fouqué and Lévy (1879) to the triclinic. The true symmetry, corresponding to the molecular structure which they possess or tend to possess at ordinary temperatures, is in doubt, but it has been shown (Klein, Penfield) that at 500° to 600° sections become isotropic; and further (Rosenbusch), that the twinning striations disappear on heating, to reappear again in new position on cooling. Sections ordinarily show twinning-lamellæ ‖ *d* (110); in some cases a bisectrix (+) is normal to what corresponds to a cubic face, the axial angle being very small. The structure corresponds in general (Klein) to the interpenetration of three crystals, in twinning position ‖ *d*, which may be equally or unequally developed; or there may be one fundamental individual with inclosed twinning-lamellæ. Fig. 566 shows a section of a crystal (‖ *a*, 100) which is apparently made up by the twinning of three individuals.

Still again, in a limited number of cases it can be shown that the intergrowth of lamellæ having slightly different crystallographic orientation is the cause of the optical peculiarities. Prehnite is a conspicuous example of this class.

After all the various possible explanations have been applied there still remain, however, many species about which no certain conclusion can be reached. This is true, for example, of perovskite. To many of these species the theory of Mallard may probably be applicable. Indeed it may be added that much difference of opinion still exists as to the cause of the "optical anomalies" in a considerable number of cases.

LITERATURE.

*Optical Anomalies.**

Brewster. Many papers in Phil. Trans., 1814, 1815, and later; also in Ed. Trans., Ed. Phil. J., etc.

Biot. Recherches sur la polarisation lamellaire, etc. C. R., **12**, 967, 1841; **13**, 155, 391, 839, 1841; in full in Mem. de l'Institut, **18**, 539.

Volger. Monographie des Boracits. Hannover, 1857.

Marbach. Ueber die optischen Eigenschaften einiger Krystalle des tesseralen Systems. Pogg. Ann., **94**, 412, 1855.

Pfaff. Versuche über den Einfluss des Drucks auf die optischen Eigenschaften der Krystalle. Pogg. Ann., **107**, 333, 1859; **108**, 598, 1859.

Des Cloizeaux. See references on p. 160.

Reusch. Ueber die sogenannte Lamellarpolarisation des Alauns. Pogg. Ann., **132**, 618, 1867.

Rumpf. Apophyllite. Min. petr. Mitth., **2**, 369, 1870.

Hirschwald. Leucite. Min. Mitth., 227, 1875.

Lasaulx. Tridymite. Zs. Kryst., **2**, 253, 1878.

Mallard. Application des phénomènes optiques anomaux que présentent un grand nombre de substances cristallisées. Annales des Mines (Ann. Min.), **10**. pp. 60–196, 1876 (Abstract in Zs. Kryst., **1**, 309–320). See also Bull. Soc. Min., **1**, 107, 1878. Sur les propriétés optiques des mélanges de substances isomorphes et sur les anomalies optiques des cristaux. Bull. Soc. Min., **3**, 3, 1880. Also ibid., **4**, 71, 1881; **5**, 144, 1882.

Bertrand. Numerous papers in Bull. Soc. Min., 1878–1882.

Becke. Chabazite. Min. petr. Mitth., **2**, 391, 1879.

Baumhauer. Perovskite. Zs. Kryst., **4**, 187, 1879.

Tschermak. "Mimetische Formen." Zs. G. Ges., **31**, 637, 1879.

Jannettaz. Diamond. Bull. Soc. Min., **2**, 124, 1879; alum, ibid., **2**, 191; **3**, 20.

Bücking. Ueber durch Druck hervorgerufene optische Anomalien. Zs. G. Ges., **32**, 199, 1880. Also, Zs. Kryst., **7**, 555, 1883.

Arzruni and **S. Koch.** Analcite. Zs. Kryst., **5**, 483, 1881.

Klocke. Ueber Doppelbrechung regulärer Krystalle. Jahrb. Min., **1**, 53, 1880 (also **2**, 97. 13 ref.; **1**, 204, 1881, and Verh. nat. Ges. Freiburg, **8**, 31). Ueber einige optische Eigenschaften optisch anomaler Krystalle und deren Nachahmung durch gespannte und gepresste Colloide. Jahrb. Min., **2**, 249, 1881.

C. Klein. Boracite. Jahrb. Min., **2**, 209, 1880; **1**, 239, 1881; **1**, 235, 1884. Garnet. Nachr. Ges. Göttingen, 1882; Jahrb. Min., **1**, 87, 1883. Apophyllite (influence of heat). Jahrb Min., **2**, 165, 1892. Garnet, vesuvianite, etc. Ib., **2**, 68, 1895.

W. Klein. Beiträge zur Kenntniss der optischen Aenderungen in Krystallen unter dem Einflusse der Erwärmung. Zs. Kryst., **9**, 38, 1884.

Brauns. Die optischen Anomalien der Krystalle. (Preisschrift), Leipzig, 1891. Also earlier papers: Jahrb. Min., **2**, 102, 1883; **1**, 96, 1885; **1**, 47, 1887.

Ben Saude. Beitrag zu einer Theorie der Optischen Anomalien der regulären Krystalle. Lisbon, 1894. Also earlier: Analcite, Jahrb. Min. **1**, 41, 1882. Perovskite (Preisschrift), Göttingen, 1882.

IV. CHARACTERS DEPENDING UPON HEAT.

412. The more important of the special properties of a mineral species with respect to heat include the following: Fusibility; conductivity and expansion, especially in their relation to crystalline structure; change in optical characters with change of temperature; specific heat; also diathermancy, or the power of transmitting radiation, that is, ether-waves. The full discussion of these and other related subjects lies outside of the range of the present text-book. A few brief remarks are made upon them, and beyond these reference must be made to text-books on Physics and to special memoirs, some of which are mentioned in the literature (p. 233).

---

* A complete bibliography is given in the memoir by Brauns (1891), see below.

413. Fusibility.—The approximate relative fusibility of different minerals is an important character in distinguishing different species from one another by means of the blowpipe. For this purpose a scale is conveniently used for comparison, as explained in the articles later devoted to the blowpipe. Accurate determinations of the fusibility are difficult, and though of little importance for the above object, they are interesting from a theoretical standpoint. They have been attempted by various authors, for example by Joly, who employed the "meldometer" for this end. This consisted of a strip of platinum in which the mineral in powder was inclosed; it was heated to the necessary point by an electrical current. He obtained the following values for the minerals used in von Kobell's scale (Art. **474**): Stibnite, 525°; natrolite, 965°; almandite, 1265°; actinolite, 1296°; orthoclase, 1175°; bronzite, 1300°; also for quartz, 1430°.

414. Conductivity.—The conducting power of different crystallized media was early investigated by Sénarmont. He covered the faces of the substance under investigation with wax and observed the form of the figure melted by a hot wire placed in contact with the surface at its middle point. Later investigations have been made by Röntgen (who modified the method of Sénarmont), by Jannettaz, and others. In general it is found that, as regards their thermal conductivity, crystals are to be divided into the three classes noted on p. 192. In other words, the conductivity for heat seems to follow the same general laws as the propagation of light. It is to be stated, however, that experiments by S. P. Thompson and O. J. Lodge have shown a different rate of conductivity in tourmaline in the opposite directions of the vertical axis.

415. Expansion.—Expansion, that is, increase in volume upon rise of temperature, is a nearly universal property for all solids. The increment of volume for the unit volume in passing from 0° to 1° C. is called the coefficient of expansion. This quantity has been determined for a number of species. Further, the relative expansion in different directions is found to obey the same laws as the light-propagation. Crystals, as regards heat-expansion, are thus divided into the same three classes mentioned on p. 192 and referred to in the preceding article.

The amount of expansion varies widely, and, as shown by Jannettaz, is influenced particularly by the cleavage. Mitscherlich found that in calcite there was a diminution of 8′ 37″ in the angle of the rhombohedron on passing from 0° to 100° C., the form thus approaching that of a cube as the temperature increased. The rhombohedron of dolomite, for the same range of temperature, diminishes 4′ 46″; and in aragonite, for a rise in temperature from 21° to 100°, the angle of the prism diminishes 2′ 46″. In some rhombohedrons, as of calcite, the vertical axis is lengthened (and the lateral shortened), while in others, like quartz, the reverse is true. The variation is such in both cases that the birefringence is diminished with the increase of temperature, for calcite possesses negative double refraction, and quartz, positive.

It is to be noted that in general the expansion by heat, while it may serve to alter the angles of crystals, other than those of the isometric system, does not alter the zone-relations and the crystalline symmetry. In certain cases, however, the effect of heat may be to give rise to twinning-lamellæ (as in anhydrite) or to cause their disappearance (as in calcite). Rarely heat serves to develop a new molecular structure; thus, as explained in Art. **411**, boracite and leucite, which are anisotropic at ordinary temperatures, become isotropic when heated, the former to 300° the latter to 500° or 600°. The change in the optical properties of crystals produced by heat has already been noticed (Art. **404**).

416. Specific Heat.—Determinations of the specific heat of many minerals have been made by Joly, by Oeberg, and others. Some of the results reached are, as follows :

	Joly.	Oeberg.		Joly.	Oeberg.
Galena, *cryst.*	0·0541	—	Orthoclase	0·1869	0·1877
Chalcopyrite	0·1271	0·1291	Albite	0·1983	0·1976
Pyrite	0·1306	—	Amphibole, *black*	0·1963	Augite 0·1830
Hematite	0·1683	0·1645	Beryl	0·2066	0·1979
Garnet, *red cryst.*	0·1780–0·1793	0·1758	Calcite	0·2034–0·2044	0·2042
Epidote	0·1877	0·1861	Aragonite	0·2036	—

417. Diathermancy.—Besides the slow molecular propagation of heat in a body, measured by its thermal conductivity, there is also to be considered the rapid propagation of what is called radiant heat through it by the wave-motion of the ether which surrounds its molecules. This is merely a part of the general subject of light-propagation already fully discussed, since heat-waves, in the restricted sense, differ from light-waves only in their relatively greater length. The degree of absorption exerted by the body is measured by its diathermancy, which corresponds to transparency in light. In this sense halite, sylvite, and fluorite are highly *diathermanous*, since they absorb but little of the heat-waves passing through them; on the other hand, selenite and, still more, alum are comparatively *athermanous*, since while transparent to the short light-waves they absorb the long heat-waves, transforming the energy into that of sensible heat. Measurements of the diathermancy were early made by Melloni, later by Tyndall, Langley, and others.

LITERATURE.

Heat.

Mitscherlich. Pogg. Ann., **1**, 125, 1824; **10**, 137, 1827.

F. E. Neumann. Gypsum. Pogg. Ann., **27**, 240, 1833.

Sénarmont. Ann. Ch. Phys., **21**, 457, 1847; **22**, 179, 1848; also in Pogg. Ann., **73**, 191: **74**, 190; **75**, 50, 482.

Ångström. Pogg. Ann., **86**, 206, 1852.

Grailich and **von Lang.** Ber. Ak. Wien, **33**, 369, 1858.

Fizeau. Thermal expansion. C. R., **58**, 923, 1864. Ann. Ch. Phys., **2**, 143, 1864; **8**, 335, 1866; also C. R., 1864–1867.

C. Neumann. Pogg. Ann., **114**, 492, 1868

Pape. Thermic axes of blue vitriol. Wied. Ann., **1**, 126, 1877.

Röntgen. Pogg. Ann., **151**, 603, 1874; Zs. Kryst., **3**, 17, 1878.

Jannettaz. Conductivity of crystals. Bull. Soc. Geol., (3) **1**, 117, 252; **2**, 264; **3**, 499; **4**, 116, 554; **9**, 196. Bull. Soc. Min., **1**, 19, 1879. C. R., 1848, **114**, 1352, 1892.

O. J Lodge. Thermal conductivity. Phil. Mag., **5**, 110, 1878.

S. P. Thompson and **O. J. Lodge.** Conductivity of tourmaline. Phil. Mag., **8**, 18, 1879.

Arzruni. Effect of heat on refractive indices of barite, etc. Zs. Kryst., **1**, 165, 1877.

Beckenkamp. Expansion of monoclinic and triclinic crystals. Zs Kryst., **5**, 436, 1881.

H. Dufet. Effect of heat on refractive indices of gypsum. Bull. Soc. Min., **4**, 113, 191, 1881.

A. Schrauf. Sulphur. Zs. Kryst., **12**, 321, 1887; TiO_2, ibid., **9**, 433, 1884.

L. Fletcher. Expansion of crystals. Zs. Kryst., **4**, 337, 1880.

Joly. Meldometer. Ch. News, **65**, 1, 16, 1892, and Proc. Roy. Irish Acad., **2**, 38, 1891. Specific heat. Proc. Roy. Soc., **41**, 250, 352, 1887.

Oeberg. Specific heat. Oefv. Ak. Stockh., No. 8, 43, 1885.

V. CHARACTERS DEPENDING UPON ELECTRICITY AND MAGNETISM.

1. ELECTRICITY.

418. Electrical Conductivity.—The subject of the relative conducting power of different minerals is one of minor interest.* In general most minerals, except those having a metallic luster among the sulphides and oxides, are non-conductors. Only the non-conductors can show pyro-electrical phenomena, and only the conductors can give a thermo-electric current.

419. Frictional Electricity.—The development of an electrical charge on many bodies *by friction* is a familiar subject. All minerals become electric by friction, although the degree to which this is manifested differs widely. There is no line of distinction among minerals, dividing them into *positively* electric and *negatively* electric; for both electrical states may be presented by different varieties of the same species, and by the same variety in different states. The gems are in general positively electric only when polished; the diamond, however, exhibits positive electricity whether polished or not. It is a familiar fact that the electrification of amber upon friction was early observed (600 B. C.), and indeed the Greek name (ἤλεκτρον) later gave rise to the word electricity.

420. Pyro-electricity.—The simultaneous development of plus and minus charges of electricity on different parts of the same crystal when its temperature is suitably changed is called pyro-electricity. Crystals exhibiting such phenomena are said to be *pyro-electric.* This phenomenon was first observed in the case of tourmaline, which is rhombohedral-hemimorphic in crystallization, and it is particularly marked with crystals belonging to groups of relatively low symmetry, especially those of the hemimorphic type. It is possible, of course, only with non-conductors. This subject was early investigated by Riess and Rose (1843), later by Hankel, also by C. Friedel, Kundt, and others (see literature).

In all cases it is true that directions of like crystallographic symmetry show charges of like sign, while unlike directions may exhibit opposite charges. Substances not crystallized cannot show pyro-electricity. A few of the many possible examples will serve to bring out the most essential points.

Boracite (isometric-tetrahedral, p. 46) on heating exhibits + electricity on one set of tetrahedral faces and − electricity on the other. Cf. Fig. 567.

Tourmaline (rhombohedral-hemimorphic, p. 79) shows opposite charges at the opposite extremities of the vertical axis corresponding to its hemimorphic crystallization. In this and in other similar cases, the extremity which becomes positive on heating has been called the *analogous* pole, and that which becomes negative has been called the *antilogous* pole.

Calamine and *struvite* (orthorhombic-hemimorphic, p. 95) exhibit phenomena analogous to these of tourmaline.

Quartz (rhombohedral-trapezohedral, p. 82) shows + electricity on heating at the three alternate prismatic edges and − electricity at the three remaining edges; the distribution for right-handed crystals is opposite to that of left-handed. Twins may exhibit a high degree of complexity. Cf. Figs. 568, 569.

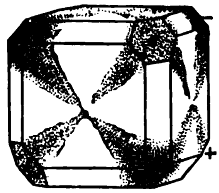
Axinite (triclinic, p. 107), when heated to 120° or 130°, has an analogous pole (Riess & Rose) at the solid angle *rxM'*; the antilogous pole at the angle *mr'M'* near plane *n*.

A very convenient and simple method for investigating the phenomena is the following, which is due to Kundt: First heat the crystal or section carefully in an air-bath; pass it several times through the flame of an alcohol lamp and then place it on a little upright cylinder of brass to cool. While cooling, a mixture of red lead and sulphur finely pulverized and previously agitated is dusted over it through a fine cloth from a suitable bellows. The positively electrified red lead collects on the parts having a negative charge, and the negatively electrified sulphur on those with a positive charge. This is illustrated by Figs. 567–569, and still better by the illustrations given by Kundt and others. (Cf. Plate III of Groth, Phys. Kryst., 1895.)

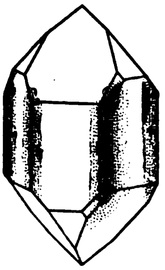
---

* On the conductivity of minerals, see Beijerinck, Jb. Min., Beil.-Bd. **11**, 403, 1898.

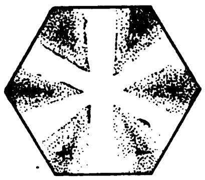
567.



568.



569.



421. Piezo-electricity.—The name *piezo-electricity* has been given to the development of electrical charges on a crystallized body by pressure. This is shown by a cleavage-mass of calcite, also by topaz. This phenomenon is most interesting where a relation can be established between the electrical excitement and the molecular structure, as is conspicuously true with quartz, tourmaline, and some other species.

This subject has been investigated by Hankel, Curie, and others, and discussed theoretically by Lord Kelvin (see literature). Hankel has also employed the term *actino-electricity*, or, better, *photo-electricity*, for the phenomenon of calling out of an electrical condition by the influence of direct radiation; fluorite is a conspicuous example.

422. Röntgen-rays in Mineralogy.—The power of different minerals to transmit the so-called X-rays, or Röntgen-rays, emitted from a suitable vacuum-tube during the discharge of an induction-coil has been investigated by Doelter.* He has found, for example, that sulphur, beryl, epidote, pyrite, etc., are nearly opaque; tourmaline less so; fluorite transmits the rays slightly, the feldspars and quartz better; corundum is nearly transparent and diamond and graphite are highly so. Diamond is easily distinguished in this way from its imitations, which are relatively highly opaque.

423. Thermo-electricity.—The contact of two unlike metals in general results in electrifying one of them positively and the other negatively. If, further, the point of contact be heated while the other parts, connected with a wire, are kept cool, a continuous current of electricity—shown, for example, by a suitable galvanometer—is set up at the expense of the heat-energy supplied. If, on the other hand, the point of junction is cooled, a current is set up in the reverse direction. This phenomenon is called *thermo-electricity*, and two metals so connected constitute a thermo-electric couple. Further it is found that different conductors can be arranged in order in a table—a so-called thermo-electric series—according to the *direction* of the current set up on heating and according to the *electromotive force* of this current. Among the metals, bismuth (+) and antimony (−) stand at the opposite ends of the series; the current passes through the connecting wire from antimony to bismuth.

---

* Jb. Min., 2, 87, 1896; 1, 256, 1897. Also Goodwin, Nature, April 30, 1896.

This subject is so far important for mineralogy, as it was shown by Bunsen that the natural metallic sulphides stand farther off in the series than bismuth and antimony, and consequently by them a higher electromotive force is produced. The thermo-electrical relations of a large number of minerals were determined by Flight.

It was early observed that some minerals have varieties which are both + and −. Rose attempted to establish a relation between the plus and minus pyritohedral forms of pyrite and cobaltite, and the positive or negative thermo-electrical character. Later investigations by Schrauf and Dana have shown, however, that the same peculiarity belongs also to glaucodot, tetradymite, skutterudite, danaite, and other minerals, and it is demonstrated by them that it cannot be dependent upon crystalline form, but rather upon chemical composition.

LITERATURE.*

Pyro-electricity, etc.

Rose. Tourmaline. Pogg. Ann., **39**, 285, 1836.
Riess and **Rose.** Pogg. Ann., **59**, 353, 1843; **61**, 659, 1844.
Kobell. Pogg. Ann., **118**, 594, 1863.
Hankel. Pogg. Ann., **49**, 493; **50**, 237, 1840; **61**, 281, 1844. Many important papers in Abhandl. K. Sächs. Ges., 1865 and later; also Wied. Ann., **2**, 66, 1877; **11**, 269, 1880, etc.
J. and **P. Curie.** C. R., **91**, 294, 383, 1880; **92**, 186, 350, 1881; **93**, 204, 1882.
Kundt. Ber. Ak. Berlin, 421, 1883; Wied. Ann., **20**, 592, 1893.
Kolenko. Quartz. Zs. Kr., **9**, 1, 1884.
C. Friedel. Sphalerite, etc. Bull. Soc. Min., **2**, 31, 1879.
C. Friedel and **Curie.** Sphalerite, boracite. Bull. Soc. Min., **6**, 191, 1883.
Mack. Boracite. Zs. Kr., **8**, 503, 1883.
Voigt. Abhandl. Ges. Göttingen, **36**, 99, 1890.
Kelvin Phil. Mag., **36**, 331, 453, 1893.
G. S. Schmidt. Photo-electricity of fluorite. Wied. Ann., **62**, 407, 1897.

Thermo-electricity.

Marbach. C. R., **45**, 705, 1857.
Bunsen. Pogg. Ann., **123**, 505, 1864.
Friedel. Ann. Ch. Phys., **17**, 79, 1869; C. R., **78**, 508, 1874.
Rose. Pyrite and cobaltite. Pogg. Ann., **142**, 1, 1871.
Schrauf and **E. S. Dana.** Ber. Ak. Wien, **69** (1), 142, 1874; Am. J. Sc., **8**, 255, 1874.

2. MAGNETISM.

424. Magnetic Minerals. Natural Magnets.—A few minerals in their natural state are capable of being attracted by a strong steel magnet; they are said to be *magnetic.* This is conspicuously true of magnetite, the magnetic oxide of iron; also of pyrrhotite or magnetic pyrites, and of some varieties of native platinum (especially the variety called iron-platinum).

A number of other minerals, as hematite, franklinite, etc., are in some cases attracted by a steel magnet, but probably in most if not all cases because of admixed magnetite (but see Art. **426**). Occasional varieties of the three minerals mentioned above, as the lodestone variety of magnetite, exhibit themselves the attracting power and polarity of a true magnet. They are then called *natural magnets*. In such cases the magnetic polarity has probably been derived from the inductive action of the earth, which is itself a huge magnet.

---

* See Liebisch, Phys. Krystallographie, 1891, for a full discussion of the topics briefly touched upon in the preceding pages, also for references to original articles.

425. Paramagnetism. Diamagnetism.—In a very strong magnetic field, as that between the poles of a very powerful electromagnet, all minerals, as indeed all other substances, are influenced by the magnetic force. According to their behavior they are divided into two classes, the *paramagnetic* and *diamagnetic;* those of the former appear to be attracted, those of the latter to be repelled. For purposes of experiment the substance in question, in the form of a rod, is suspended on a horizontal axis between the poles of the magnet. If paramagnetic, it takes a position parallel to the magnetic axis; if diamagnetic, it sets transversely to it. Iron, cobalt, nickel, manganese, platinum are paramagnetic; silver, copper, bismuth are diamagnetic. Among minerals compounds of iron are paramagnetic, as siderite, also diopside; further beryl, dioptase. Diamagnetic species include calcite, zircon, wulfenite, etc.

By the use of a sphere it is possible to determine the relative amount of magnetic induction in different directions of the same substance. Experiment has shown that in isometric crystals the magnetic induction is alike in all directions; in those optically uniaxial, that there is a direction of maximum and, normal to it, one of minimum magnetic induction; in biaxial crystals, that there are three unequal magnetic axes, the position of which may be determined. In other words, the magnetic relations of the three classes of crystals are analogous to their optical relations.

426. Corresponding to the facts just stated, that all compounds of iron are paramagnetic, it is found that a sufficiently powerful electromagnet attracts all minerals containing iron, though except in the cases given in Art. **424** a bar magnet has no sensible influence upon them; hence the efficiency of the electromagnetic method of separating ores.

Plücker* determined the magnetic attraction of a number of substances compared with iron taken as 100,000. For example, for magnetite he obtained 40,227; for hematite, crystallized, 533, massive, 134; limonite, 71; pyrite, 150.

LITERATURE.

Magnetism.

Plücker. Pogg. Ann., **72**, 315, 1847; **76**, 576, 1849; **77**, 447, 1849; **78**, 427, 1849; **86**, 1, 1852.

Plücker and **Beer**. Pogg. Ann., **81**, 115. 1850; **82**, 42, 1852.

Faraday. Phil. Trans., 1849–1857, and Experimental Researches, Series XXII., XXVI., XXX.

W. Thomson (Lord Kelvin). Theory of Magnetic Induction. Brit. Assoc., 1850, pt. 2, 23; Phil. Mag., **1**, 177, 1851, etc. Reprint of Papers on Electrostatics and Magnetism, 1872.

Tyndall. Phil. Mag., **2**, 165, 1851; **10**, 153, 257, 1855; **11**, 125, 1856; Phil. Trans., 1855, 1. Researches on diamagnetism and magne-crystallic action. London 1870.

Knoblauch and **Tyndall.** Pogg. Ann., **79**, 233; **81**, 481, 1850 (Phil. Mag., **36**, **37**, 1850).

Rowland and **Jacques**. Bismuth, Calcite. Am. J. Sc., **18**, 360, 1879.

Tumlirz. Quartz. Wied. Ann., **27**, 133, 1886.

Koenig. Wied. Ann., **31**, 273, 1887.

Stenger. Calcite. Wied. Ann., **20**, 304, 1883; **35**, 331, 1888.

---

* Pogg. Ann., **74**, 348, 1848.

VI. TASTE AND ODOR.

In their action upon the senses a few minerals possess *taste,* and others under some circumstances give off *odor.*

427. **Taste** belongs only to soluble minerals. The different kinds of taste adopted for reference are as follows:

1. *Astringent:* the taste of vitriol.
2. *Sweetish astringent:* taste of alum.
3. *Saline:* taste of common salt.
4. *Alkaline:* taste of soda.
5. *Cooling:* taste of saltpeter.
6. *Bitter:* taste of Epsom salts.
7. *Sour:* taste of sulphuric acid.

428. **Odor.**—Excepting a few gaseous and soluble species, minerals in the dry unchanged state do not give off odor. By friction, moistening with the breath, and the elimination of some volatile ingredient by heat or acids, odors are sometimes obtained which are thus designated:

1. *Alliaceous:* the odor of garlic. Friction of arsenical iron elicits this odor; it may also be obtained from arsenical compounds by means of heat.
2. *Horse-radish odor:* the odor of decaying horse-radish. This odor is strongly perceived when the ores of selenium are heated.
3. *Sulphurous:* friction elicits this odor from pyrite, and heat from many sulphides.
4. *Bituminous:* the odor of bitumen.
5. *Fetid:* the odor of sulphureted hydrogen or rotten eggs. It is elicited by friction from some varieties of quartz and limestone.
6. *Argillaceous:* the odor of moistened clay. It is obtained from serpentine and some allied minerals, after moistening them with the breath; others, as pyrargillite, afford it when heated.

429. **Feel.**—The FEEL is a character which is occasionally of some importance; it is said to be *smooth* (sepiolite), *greasy* (talc), *harsh,* or *meager,* etc. Some minerals, in consequence of their hygroscopic character, *adhere to the tongue* when brought in contact with it.

PART III. CHEMICAL MINERALOGY.

GENERAL PRINCIPLES OF CHEMISTRY AS APPLIED TO MINERALS.

430. Minerals, as regards their chemical constitution, are either the uncombined elements in a native state, or definite compounds of these elements formed in accordance with chemical laws. It is the object of Chemical Mineralogy to determine the chemical composition of each species; to show the chemical relations of different species to each other where such exist; and also to explain the methods of distinguishing different minerals by chemical means. It thus embraces the most important part of Determinative Mineralogy.

In order to understand the chemical constitution of minerals, some knowledge of the fundamental principles of Chemical Philosophy is required; and these are here briefly recapitulated.

431. Chemical Elements.—Chemistry recognizes about seventy substances which cannot be decomposed, or divided into others, by any process of analysis at present known; these substances are called the chemical *elements*. A list of them is given in a later article (**436**); common examples are: Oxygen, nitrogen, hydrogen, chlorine, gold, silver, sodium, etc.

432. Atom. Molecule.—The study of the chemical properties of substances and of the laws governing their formation has led to the belief that there is for each element a definite, indivisible mass, which is the smallest particle which can play a part in chemical reactions; this indivisible unit is called the *atom*.

With some rare exceptions, the atom cannot exist alone, but unites by the action of what is called chemical force, or chemical affinity, with other atoms of the same or different kind to form the *molecule*. The molecule, in the chemical sense, may be defined as the smallest particle into which a given kind of substance can be subdivided without undergoing chemical decomposition. For example, two *atoms* of hydrogen unite to form a *molecule* of hydrogen gas. Again, one atom of hydrogen and one of chlorine form a molecule of hydrochloric acid gas; two atoms of hydrogen and one of sulphur form a molecule of the gas hydrogen sulphide.

433. Physical Molecules.—An important distinction must be made between the simple chemical molecules, regarded as made up of the smallest possible number of the atoms of each kind, united in the given proportion, and the actual *physical molecules* which together build up the structure of a particular

ELEMENTS OF THE RARE EARTHS
Geochemistry-Clarke- 1924

		Atomic wei
1-Cerium	Ce	140.25
2-Dysprosium	Dy	162.5
3-Erbium	Er	167.7
4-Europium	Eu	152.0
5-Gadolinium	Gd	157.3
6-Holmium	Ho	163.5
7-Lanthanum	La	139.0
8-Lutecium	Lu	175.0
9-Neodymium	Fe	144.3
10-Praseodymium	Pr	140.9
11-Samarium	Sa	150.4
12-Scandium	Sc	45.1
13-Terbium	Tb	159.2
14-Thulium	Tm	169.9
15-Ytterbium	Yb	173.5
16- Yttrium	Yt	89.3

U.S.G.S.Bull. 720,p. 728.

mass of matter. These
being made up of a nur
the respective atoms in
possible to determine tl
but in the case of liquid
For example, it is c
atoms of hydrogen and
unite to build up a sn
elements hydrogen and
as if made up of many
case of solids to fix the
to regard it as a chemic
434. Atomic Weight
better expressed, the m
hydrogen taken as the
nearly sixteen times tha
this number is called th
the relation between th
here to speak; the resu
p. 241.
435. Symbol. Form
letters, often of its Lati
chemical notation the c
it enters. Thus O is t
Fe (from *ferrum*) of ir
symbol is always undei
element expressed by i
atom. If twice this qu
by a small subscript nu
Sb_2S_3 means a compou
sulphur, or of 2 × 120
This expression, Sb_2
it expresses in briefest
mineral albite is NaAlS
Strictly speaking, su
express only the actual
atoms of each element
constitution. A formu
rational, structural, or c
436. Table of the E
definitely established e
atomic weights.*
Of the elements gi
small number, say twel
the earth and the water
cerned in the compositic
iron, calcium, magnesium,
present in water, nitrogen in the air, and carbon in all animal and vegetable substances. Only a very few of the elements occur as such in nature, as native gold, native silver, native sulphur, etc.

---

* These correspond in value to those commonly accepted, and are given accurate to one decimal place. In strict chemical sense the atomic weight of oxygen is 15·96, etc.

Of the elements, oxygen, hydrogen, nitrogen, chlorine, and fluorine are gases; bromine is a volatile liquid; mercury is also a liquid, but the others are solids under ordinary conditions.

	Symbol.	At. Weight.		Symbol.	At. Weight.
Aluminium, Aluminum	Al	27	Manganese	Mn	54·8
Antimony (*Stibium*)	Sb	120	Mercury (*Hydrargyrum*)	Hg	199·8
Argon	A	39·9	Molybdenum	Mo	96
Arsenic	As	74·9	Nickel	Ni	58·6
Barium	Ba	137	Niobium	Nb	93·7
Beryllium	Be (or Gl)	9·1	Nitrogen	N	14
Bismuth	Bi	207·5	Osmium	Os	191
Boron	B	10·9	Oxygen	O	16
Bromine	Br	79·8	Palladium	Pd	106·2
Cadmium	Cd	111·7	Phosphorus	P	31
Cæsium	Cs	58·7	Platinum	Pt	194·3
Calcium	Ca	39·9	Potassium (*Kalium*)	K	39
Carbon	C	12	Rhodium	Rh	104·1
Cerium	Ce	141	Rubidium	Rb	85·2
Chlorine	Cl	35·4	Ruthenium	Ru	103·5
Chromium	Cr	52·5	Scandium	Sc	44
Cobalt	Co	58·7	Selenium	Se	78·9
Columbium, see *Niobium*.			Silicon	Si	28
Copper (*Cuprum*)	Cu	63·2	Silver (*Argentum*)	Ag	107·7
Didymium	Di	142	Sodium (*Natrium*)	Na	23
Erbium	Er	166	Strontium	Sr	87·3
Fluorine	F	19·1	Sulphur	S	32
Gallium	Ga	69·9	Tantalum	Ta	182
Germanium	Ge	73·3	Tellurium	Te	125
Glucinum, see *Beryllium*.			Thallium	Tl	203·7
Gold (*Aurum*)	Au	196·7	Thorium	Th	232
Helium	He	4·4	Tin (*Stannum*)	Sn	117·4
Hydrogen	H	1	Titanium	Ti	48
Indium	In	113·4	Tungsten (*Wolframium*)	W	183·6
Iodine	I	126·5	Uranium	U	240
Iridium	Ir	192·5	Vanadium	V	51·1
Iron (*Ferrum*)	Fe	55·9	Ytterbium	Yt	172·6
Lanthanum	La	138	Yttrium	Y	89
Lead (*Plumbum*)	Pb	206·4	Zinc	Zn	65·1
Lithium	Li	7	Zirconium	Zr	90·4
Magnesium	Mg	24			

437. Metals and Non-metals.—The elements may be divided into two more or less distinct classes, the metals and the non-metals. Between the two lie a number of elements sometimes called the semi-metals. The *metals*, as gold, silver, iron, sodium, are those elements which, *physically* described, possess to a more or less perfect degree the fundamental characters of the ideal metal, viz.: malleability, metallic luster (and opacity to light), conductivity for heat and electricity; moreover, *chemically* described, they commonly play the part of the positive or basic element in a simple compound, as later defined (Arts. **446–449**). The *non-metals*, as sulphur, carbon, silicon, etc., also the gases, as oxygen, chlorine, etc., have none of the physical characters alluded to: they are, if solids, brittle, often transparent to light-radiation, are poor conductors for heat and electricity. Chemically expressed, they usually play the negative or acid part in a simple compound.

The so-called *semi-metals*, or metalloids, include certain elements, as tellurium, arsenic, antimony, bismuth, which have the physical characters of a metal to a less perfect degree (*e.g.*, they are more or less brittle); and, more important than this, they often play the part of the acidic element in the compound into which they enter. These points are illustrated later.

It is to be understood that the distinctions between the classes of the elements named cannot be very sharply applied. Thus the typical metallic characters mentioned are possessed to a very unequal degree by the different substances classed as metals; for example, by silver and tin. Corresponding to this a number of the true metals, as tin and manganese, play the part of an acid in numerous salts. Further, the mineral magnetite, $\overset{II}{Fe}\overset{III}{Fe}_2O_4$, is often described as an *iron ferrate*; so that in this compound the same element would play the part of both acid and base.

438. Positive and Negative Elements.—It is common to make a distinction between the *electro-positive* and *electro-negative* element in a compound. The passage of a sufficiently strong electrical current through a chemical compound in many cases results in its decomposition (or electrolysis) into its elements or parts. In such cases it is found that for each compound the atoms of one element collect at the negative pole (the cathode) and those of the other at the positive pole (the anode). The former is called the electro-positive element and the latter the electro-negative element. Thus in the electrolysis of water (H_2O) the hydrogen collects at the cathode and is hence called positive, and the oxygen at the anode and is called negative. Similarly, in hydrochloric acid (HCl) the hydrogen is thus shown to be positive, the chlorine negative. This distinction is also carried to complex compounds, as copper sulphate ($CuSO_4$), which by electrolysis is broken into Cu, which is found to be electro-positive, and SO_4 (the last separates into SO_3, forming H_2SO_4 and free oxygen).

For reasons which will be explained later, the positive element is said to play the basic part, the negative the acidic. The metals, as already stated, in most cases belong to the former class, the non-metals to the latter, while the semi-metals may play both parts.

It is common in writing the formula to put the positive or basic element first, thus H_2O, H_2S, HCl, H_2SO_4, Sb_2S_3, As_2O_3, AsH_3, $NiSb$, $FeAs_2$. Here it will be noted that antimony (Sb) and arsenic (As) are positive in some of the compounds named but negative in the others.

439. Periodic Law.—In order to understand the relations of the chief classes of chemical compounds represented among minerals, as still more their further subdivision, down finally to the many *isomorphous groups*—groups of species having analogous composition and closely similar form, as explained in Art. 456—the fundamental relations and grouping of the elements must be understood, especially as developed of recent years and shown in the so-called Periodic Law.*

Although the subject can be only briefly touched upon, it will be useful to give here the general distribution of the elements into Groups and Series, as presented in the Principles of Chemistry (Engl. Ed., 1891) of D. Mendeléeff, to whom is due more than any one else the development of the Periodic Law. A few remarks are added on the grouping of the elements as illustrated by mineral compounds; artificial compounds show these relations still more fully and clearly. For the thorough explanation of this subject, more particularly as regards the periodic or progressive relation between the atomic weights and various properties of the elements, the reader is referred to the work above mentioned or to one of the many other excellent modern text-books of chemistry.

The relations of some of the elements of the first group are exhibited by the isomorphism (see Art. 456, also the description of the various groups and species here referred to, which are given in Part IV of this work) of NaCl, KCl, AgCl; or again of $LiMnPO_4$ and $NaMnPO_4$, etc. In the second group,

---

* The relations here brought out are important, even if the validity of the Periodic Law is less general than has been supposed.

Groups . . .	I	II	III	IV	V	VI	VII	VIII
Series 1 . . .	H	—	—	RH_4	RH_3	RH_2	RH	Hydrogen Compounds.
" 2 . . .	Li	Be	B	C	N	O	F	
" 3 . . .	Na	Mg	Al	Si	P	S	Cl	
" 4 . . .	K	Ca	Se	Ti	V	Cr	Mn	Fe Co Ni Cu
" 5 . . .	(Cu)	Zn	Ga	Ge	As	Se	Br	55.9 \ 58.7 \ 58.4 / 63.2
" 6 . . .	Rb	Sr	Y	Zr	Nb	Mo	—	Ru Rh Pb Ag
" 7 . . .	Ag	Cd	In	Gn	Sb	Te	I	103.5 - 104.1 106.4 \ 107.9
" 8 . . .	Cs	Ba	La	Ce	Di?	—	—	
" 9 . . .	—	—	—	—	—	—	—	
" 10 . . .	—	—	Yb 172.6	—	Ta 182.	W 183.6	—	Os Ir Pt Ag
" 11 . . .	Au 196.7	Hg 199.8	Tl 203.7	Pb 206.4	Bi 207.5	—	—	191 192.5 194.3 1029
" 12 . . .	—	—	—	—	—	U 240.	—	
	R_2O	R_2O_2 RO	R_2O_3	R_2O_4 RO_2	R_2O_5	R_2O_6 RO_3	R_2O_7	Higher Oxides RO_4

reference may be made to the isomorphism of the carbonates and sulphates (p. 250) of calcium, barium, and strontium; while among the sulphides, ZnS, CaS, and HgS are doubly related. In the third group, we find boron and aluminium often replacing one another among silicates. In the fourth group, the relations of silicon and titanium are shown in the titano-silicates, while the compounds TiO_2, SnO_2, PbO_2 (and MnO_2), also $ZrSiO_4$ and $ThSiO_4$, have closely similar form. In the fifth group, many compounds of arsenic, antimony, and bismuth are isomorphous among metallic compounds, while the relations of phosphorus, vanadium, arsenic, also antimony, are shown among the phosphates, vanadates, arsenates, and antimonates; again the mutual relations of the niobates and tantalates are to be noted.

In the sixth group, the strongly acidic elements, sulphur, selenium, tellurium, are all closely related, as seen in many sulphides, selenides, tellurides; further, the relations of sulphur and chromium, and similarly of both of these to molybdenum and tungsten, are shown among many artificial sulphates, chromates, molybdates, and tungstates.

In the seventh group the relations of the halogens are too well understood to need special remark. In the eighth group, we have Fe, Co, Ni alloyed in meteoric iron, and their phosphates and sulphates are in several cases closely isomorphous; further, the relation of the iron series to that of the platinum series is exhibited in the isomorphism of FeS_2, FeAsS, $FeAs_2$, etc., with $PtAs_2$ and probably RuS_2.

440. Combining Weight.—Chemical investigation proves that the mass of a given element entering into a compound is always proportional either to its atomic weight or to some simple multiple of this; the atomic weight is hence also called the *combining weight.* Thus in rock salt, sodium chloride, the masses involved of sodium and chlorine present are found by analysis to be equal to 39·4 and 60·6 in 100 parts, and these numbers are in proportion to 23 : 35·4, the atomic weights of sodium and chlorine; hence it is concluded that one atom of each is present in the compound. The formula is, therefore, $NaCl$. In calcium chloride, by the same method the masses present are found to be proportional to 39·9 : 70·8, that is, to $39·9 = 2 \times 35·4$; hence the formula is $CaCl_2$.

Still again, a series of compounds of nitrogen with oxygen is known in which the ratios of the masses of the two elements are as follows: (1) 28 : 16, (2) 14 : 16, (3) 28 : 48, (4) 14 : 32, (5) 28 : 80. It is seen at once that these must have the formulas (1) N_2O, (2) NO, (3) N_2O_3, (4) NO_2, (5) N_2O_5. On the contrary, atmospheric air which contains these elements in about the ratio of 76·8 to 23·2 cannot be a chemical compound of these elements, since (aside from other considerations) these numbers are not in the ratio of $n \times 14 : m : 16$ where n and m are simple whole numbers.

441. Molecular Weight.—The molecular weight is the weight of the molecule of the given substance, expressed in terms of the mass of the hydrogen atom as unit. The molecular weight of hydrogen is 2 because the molecule can be shown to consist of two atoms. The molecular weight of hydrochloric acid (HCl) is 36·4, of water vapor (H_2O) it is 18, of hydrogen sulphide (H_2S) it is 34.

Since, according to the law of Avagadro, like volumes of different gases under like conditions as to temperature and pressure contain the same number of molecules, it is obvious that the molecular weight of substances in the form of gas can be derived directly from the relative density or specific gravity. If the density is referred to hydrogen, whose molecular weight is 2, it will be always true that the molecular weight is twice the density in the state of a gas and *vice versa.* Thus the observed density of carbon dioxide (CO_2) is 22, hence its molecular weight must be 44. It is this principle that makes it possible in the case of a gas to fix the constitution of the molecule when the ratio in number of the atoms entering into it has been determined by analysis. In the case of solids, where the constitution of the molecule in general cannot be fixed, it is best, as already stated, to write the molecular formula in its simplest form, as $NaAlSi_3O_8$ for albite. The sum of the weights of the atoms present is then taken as the molecular weight.

442. Valence.—The valence of an element is given by the number of its atoms which are required to unite with one unit atom, as of hydrogen or chlorine. Thus, using the examples of Art. **440**, in $NaCl$, since one atom of sodium unites with one of chlorine, its valence is one; or in other words, it is said to be *univalent*, and is called a monad. Further, calcium (as in $CaCl_2$), also barium, etc., are bivalent; gold is (usually) trivalent; tin is tetravalent, etc. The valence may be expressed by the number of bonds by which one element in a compound is united to another, thus:

$$Na{-}Cl, \qquad Ba{=}Cl_2, \qquad Au{\equiv}Cl_3, \qquad Sn{\equiv}Cl_4, \qquad \text{etc.}$$

The valences of the common elements, expressed by their symbols, are as follows:

Univalent: H, Cl, Br, I, F; Li, Na, K, Rb, Cs, Ag.
Bivalent: O, S, Se, Te; Be, Mg, Ca, Sr, Ba, Pb, Hg, Cu, Zn, Co, Ni.
Trivalent: B, Au; probably also Al, Fe, Mn, Cr.
Tetravalent: C, Si, Ti, Zr, Sn.
Pentavalent: N, P, As, Sb, V, Bi, Nb, Ta.

The above list, though convenient for reference, is not to be taken as complete or final. A considerable number of the elements show a different valence in different compounds. Thus both Sb_2O_3 and Sb_2O_5 are known; also FeS, Fe_2O_3 and FeS_2; Cu_2Cl_2, $CuCl_2$, and similarly $Cu_2S(Cu_2O)$ and $CuS(CuO)$, etc. In certain cases the composition of two compounds of the same elements may be made consistent with each other, by an assumption as to the possible grouping of the atoms. Thus in cupric chloride, $CuCl_2$, or cupric oxide, CuO, copper is bivalent as usual. But the cuprous compounds, Cu_2Cl_2 and Cu_2O, also occur, and for them the formulas may be written

$$\mathrm{Cl{-}Cu{-}Cu{-}Cl} \qquad \text{and} \qquad \mathrm{(Cu{-}Cu){=}O}.$$

Again, the elements Al, Fe, Mn, Cr, which form the compounds $AlCl_3$, Al_2O_3, etc., are sometimes called tetravalent and the formula of the oxide written, for example, $(Al = Al) \equiv O_3$.

443. **Chemical Reactions.**—When solutions of two chemical substances are brought together, in many cases they react upon each other with the result of forming new compounds out of the elements present; this phenomenon is called a *chemical reaction*. One of the original substances may be a gas, and in many cases similar results are obtained from a liquid and a solid, or less often from two solids.

For example, solutions of sodium chloride (NaCl) and silver nitrate ($AgNO_3$) react on each other and yield silver chloride (AgCl) and sodium nitrate ($NaNO_3$). This is expressed in chemical language as follows:

$$NaCl + AgNO_3 = AgCl + NaNO_3.$$

This is a chemical equation, the sign of equality meaning that equal weights are involved both before and after the reaction.

Again, hydrochloric acid (HCl) and calcium carbonate ($CaCO_3$) yield calcium chloride ($CaCl_2$) and carbonic acid (H_2CO_3); which last breaks up into water (H_2O) and carbon dioxide (CO_2), the last going off as a gas with effervescence. Hence

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

444. **Radicals.**—A compound of two or more elements according to their relative valence in which all their bonds are satisfied is said to be *saturated*. This is true of H_2O, or, as it may be written, H—O—H. If, however, one or more bonds is left unsatisfied, the resulting combination of elements is called a *radical*. Thus —O—H, called briefly hydroxyl, is a common radical, having a valence of one, or, in other words, univalent; NH_4 is again a univalent radical; so, too, (CaF), (MgF) or (AlO). Radicals often enter into a compound like a simple element; for example, in ammonium chloride, NH_4Cl, the univalent radical NH_4 plays the same part as the univalent element Na in NaCl. In the chemical composition of mineral species, the commonest radical is hydroxyl (—O—H) already defined. Other examples are (CaF) in apatite (see Art. 456), (MgF) in wagnerite, (AlO) in many basic silicates, etc.

445. **Chemical Compound.**—A chemical compound is a combination of two or more elements united by the force of chemical attraction. It is always true of it, as before stated (Art. 440), that the elements present are combined in the proportion of their atomic weights or some simple multiples of these. A substance which does not satisfy this condition is not a compound, but only a mechanical mixture.

Examples of the simpler class of compounds are afforded by the *oxides*, or compounds of oxygen with another element. Thus, among minerals we have Cu_2O, cuprous oxide (cuprite); ZnO, zinc oxide (zincite); Al_2O_3, alumina (corundum); SnO_2, tin dioxide (cassiterite); SiO_2, silicon dioxide (quartz); As_2O_3, arsenic trioxide (arsenolite).

Another simple class of compounds are the *sulphides* (with the selenides, tellurides, arsenides, antimonides, etc.), compounds in which sulphur (selenium, tellurium, arsenic, antimony, etc.) plays the same part as oxygen in the oxides. Here belong Cu_2S, cuprous sulphide (chalcocite); ZnS, zinc sulphide (sphalerite); PbTe, lead telluride (altaite); FeS_2, iron disulphide (pyrite); Sb_2S_3, antimony trisulphide (stibnite).

446. Acids.—The more complex chemical compounds, an understanding of which is needed in a study of minerals, are classed as acids, bases, and salts; the distinctions between them are important.

An *acid* is a compound of hydrogen, or hydroxyl, with a non-metallic element (as chlorine, sulphur, nitrogen, phosphorus, etc.), or a radical containing these elements. In them the hydrogen atoms may be replaced by metallic atoms; the result being then the formation of a salt (see Art. **448**). Acids in general turn blue litmus paper red and have a sharp, sour taste. The following are familiar examples:

HCl, hydrochloric acid,	$H - Cl$.
HNO_3, nitric acid,	$(HO) = NO_2$.
H_2CO_3, carbonic acid,	$(HO)_2 = CO$.
H_2SO_4, sulphuric acid,	$(HO)_2 = SO_2$.
H_2SiO_3, metasilicic acid,	$(HO)_2 = SiO$.
H_3PO_4, phosphoric acid,	$(HO)_3 \equiv PO$.
H_4SO_4, orthosilicic acid,	$(HO)_4 \equiv Si$.

The full explanation of the constitution of the different acids requires a more detailed discussion than is possible here. The second series of formulas given above must serve as suggestions in this direction.

It is to be noted that with a given acid element several acids are possible. Thus normal, or orthosilicic, acid is H_4SiO_4, in which the bonds of the element silicon are all satisfied by the hydroxyl (HO). But the removal of one molecule of water, H_2O, from this gives the formula H_2SiO_3, or metasilicic acid.

Acids which, like HNO_3, contain one atom of hydrogen that may be replaced by a metallic atom (*e.g.*, in KNO_3) are called *monobasic*. If, as in H_2CO_3 and H_2SO_4, there are two atoms (*e.g.*, in $CaCo_3$, $BaSO_4$) the acids are *dibasic*. Similarly H_3PO_4 is *tribasic*, etc.

Most acids are liquids (or gases), and hence acids are represented very sparingly among minerals; $B(OH)_3$, boric acid (sassolite), is an illustration.

447. Bases.—The *bases*, or hydroxides as they are also called, are compounds which may be regarded as formed of a metallic element (or radical) and the univalent radical hydroxyl, $-(OH)$; or in other words, of an oxide with water. Thus potash, K_2O, and water, H_2O, form $2K(OH)$, or potassium hydroxide; also $CaO + H_2O$ similarly give $Ca(OH)$ or calcium hydroxide. In general, when soluble in water, bases give an alkaline reaction with turmeric paper or red litmus paper, and they also neutralize an acid, as explained in the next article. Further, the bases yield water on ignition, that is, at a temperature sufficiently high to break up the compound.

Among minerals the bases are represented by the hydroxides, or hydrated oxides, as $Mg(OH)_2$, magnesium hydrate (brucite); $Al(OH)_3$, aluminium hydrate (gibbsite); also, $(AlO)(OH)$, diaspore, etc.

448. Salts.—A third class of compounds are the *salts;* these may be regarded as formed chemically by the reaction of a base upon an acid, or, in other words, by the neutralization of the acid. Thus calcium hydrate and sulphuric acid give calcium sulphate and water:

$$\mathrm{Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O.}$$

Here calcium sulphate is the salt, and in this case the acid, sulphuric acid, is said to be neutralized by the base, calcium hydroxide. It is instructive to compare the formulas of a base, an acid, and the corresponding salt, as follows:

Base, $\mathrm{Ca(OH_2)}$; *Acid,* $\mathrm{H_2SO_4}$; *Salt,* $\mathrm{CaSO_4}$.

Here it is seen that a salt may be simply described as formed from an acid by the replacement of the hydrogen atom, or atoms, by a metallic element or radical.

449. Typical Salts.—The commonest types of salts represented among minerals are the following:

Chlorides: salts of hydrochloric acid, HCl; as AgCl, silver chloride (cerargyrite).

Nitrates: salts of nitric acid, $\mathrm{HNO_3}$; as $\mathrm{KNO_3}$, potassium nitrate (niter).

Carbonates: salts of carbonic acid, $\mathrm{H_2CO_3}$; as $\mathrm{CaCO_3}$, calcium carbonate (calcite and aragonite).

Sulphates: salts of sulphuric acid, $\mathrm{H_2SO_4}$; as $\mathrm{CaSO_4}$, calcium sulphate (anhydrite).

Phosphates: salts of phosphoric acid, $\mathrm{H_3PO_4}$; as $\mathrm{Ca_3(PO_4)_2}$, calcium phosphate.

Silicates: several classes of salts are here included. The most common are the salts of metasilicic acid, $\mathrm{H_2SiO_3}$; as $\mathrm{MnSiO_3}$, manganese metasilicate (rhodonite). Also salts of orthosilicic acid, $\mathrm{H_4SiO_4}$; as $\mathrm{Mn_2SiO_4}$, manganese orthosilicate (tephroite).

Numerous other classes of salts are also included among mineral species; their composition, as well as that of complex salts of the above types, is explained in the descriptive part of this work.

450. Normal, Acid, and Basic Salts.—A *neutral* or *normal salt* is one in which the basic element completely neutralizes the acid, or, in other words, one of the type already given as examples, in which *all* the hydrogen atoms of the acid have been replaced by metallic atoms or radicals. Thus, $\mathrm{K_2SO_4}$ is normal potassium sulphate, but $\mathrm{HKSO_4}$, on the other hand, is acid potassium sulphate, since in the acid $\mathrm{H_2SO_4}$ only one of the bonds is taken by the basic element potassium. Salts of this kind are called *acid salts.* The formula in such cases may be written * as if the compound consisted of a normal salt and an acid; thus, for the example given. $\mathrm{K_2SO_4.H_2SO_4}$.

A *basic salt* is one in which the acid part of the compound is not sufficient to satisfy all the bonds of the base. Thus malachite is a basic salt—basic carbonate of copper—its composition being expressed by the formula $\mathrm{Cu_2(OH)_2CO_3}$. This may be written $\mathrm{CuCO_3.Cu(OH)_2}$, or $\mathrm{(Cu_2)}\begin{array}{l}=\mathrm{CO_3}\\=\mathrm{(OH)_2}\end{array}$. The majority of minerals consist not of simple salts, as those noted above, but of more or less complex double salts in which several metallic elements are present. Thus common grossular garnet is an orthosilicate containing both calcium and aluminium as bases; its formula is $Ca_3Al_2(SiO_4)_3$.

---

* This early form of writing the composition explains the name often given to the compound, namely, in this case, "bisulphate of potash."

451. Sulpho-salts.—The salts thus far spoken of are all oxygen salts. There are also others, of analogous constitution, in which sulphur takes the place of the oxygen; they are hence called *sulpho-salts*. Thus normal sulpharsenious acid has the formula H_3AsS_3, and the corresponding silver salt is Ag_3AsS_3, the mineral proustite. Similarly the silver salt of the analogous antimony acid is Ag_3SbS_3, the mineral pyrargyrite. From the normal acids named, a series of other hypothetical acids may be derived, as $HAsS_2$, $H_4As_2S_5$, etc.; these acids are not known to exist, but their salts are important minerals. Thus zinkenite, $PbSb_2S_4$, is a salt of the acid H_2SbS_4, and jamesonite, $Pb_2Sb_2S_5$, of the acid $H_4Sb_2S_5$, etc.

452. Water of Crystallization.—As stated in Art. **447**, the hydroxides, or bases and further basic salts in general, yield water when ignited. Thus calcium hydroxide Ca(OH) breaks up on heating into CaO and H_2O, as expressed in the chemical equation

$$2Ca(OH) = 2CaO + H_2O.$$

So also the basic cupric carbonate, malachite (formula given in Art. **450**), yields water on ignition; and the same is true of the complex basic orthosilicates, like zoisite, whose formula is $(HO)Ca_2Al_3(SiO_4)_3$. It is not to be understood, however, in these or similar cases, that water as such is present in the substance.

On the other hand, there are a large number of mineral compounds which yield water readily when heated, and in which the water molecules are regarded as present as so-called *water of crystallization*. Thus, the formula of gypsum is written

$$CaSO_4 + 2H_2O,$$

and the molecules of water ($2H_2O$) are considered as water of crystallization. So, too, in potash alum, $KAl(SO_4)_2 + 12H_2O$, the water is believed to play the same part.

453. Formulas of Minerals.—The strictly empirical formula expresses the kinds and numbers of atoms of the elements present in the given compound, without attempting to show the way in which it is believed that the atoms are combined. Thus, in the case of zoisite the empirical formula is $HCa_2Al_3Si_3O_{13}$. While not attempting to represent the structural formula (which will not be discussed here), it is convenient in certain cases to indicate the atoms which there is reason to believe play a peculiar relation to each other. Thus the same formula written $(HO)Ca_2Al_3(SiO_4)_3$ shows that it is regarded as a basic orthosilicate, in other words, a basic salt of orthosilicic acid, H_4SiO_4.

Again, the empirical formula of common apatite is $Ca_5FP_3O_{12}$; but if this is written $(CaF)Ca_4(PO_4)_3$, it shows that it is regarded as a phosphate of the acid H_3PO_4, that is, $H_9(PO_4)_3$, in which the nine hydrogen atoms are replaced by four Ca atoms together with the univalent radical (CaF). In another kind of apatite the radical (CaCl) enters in the same way. Similarly to this the formula of pyromorphite is $(PbCl)Pb_4(PO_4)_3$, of vanadinite $(PbCl)Pb_4(VO_4)_3$.

Further, it is often convenient to employ the method of writing the formulas in vogue under the old dualistic system. For example,

$$\begin{aligned} CaO.CO_2 &\text{ for } CaCO_3, \\ 3CaO.Al_2O_3.3SiO_2 &\text{ for } Ca_3Al_2Si_3O_{12}, \\ 3Ag_2S.Sb_2S_3 &\text{ for } Ag_3SbS_3, \text{ etc.} \end{aligned}$$

It is no longer believed, however, that the molecular groups CaO, Al_2O_3, etc., actually exist in the molecule of the substance. But in part because these groups are what analysis of the substance affords directly, and in part because so easily retained in the memory, this method of writing is still often used.

454. Oxygen Ratio.—In the case of certain compounds, more especially the silicates, it is sometimes regarded as convenient to take note of the *oxygen ratio*, that is, the ratio in the number of oxygen atoms combined with the several elements, basic and acid. For example, the formula for grossular garnet given above is

$$Ca_3Al_2Si_3O_{12} \text{ or } 3CaO.Al_2O_3.3SiO_2.$$

Here the oxygen atoms combined with the basic elements (calcium and aluminium) and the acid element (silicon) are

$$3 : 3 : 6 \text{ or } 1 : 1 : 2,$$

or again, for the basic elements combined,

$$3 + 3 : 6 \text{ or } 1 : 1.$$

It must be noted that the oxygen ratio is in fact the ratio of the total valence of the elements of the different groups, the valence being measured by the combining power with hydrogen, while the oxygen ratio really notes the combining power with oxygen.

455. Calculation of a Formula from an Analysis.—The result of an analysis gives the proportions, in a hundred parts of the mineral, of either the elements themselves, or of their oxides or other compounds obtained in the chemical analysis. In order to obtain the atomic proportions of the elements:

Divide the percentages of the elements by the respective ATOMIC WEIGHTS; or, for those of the oxides: *Divide the percentage amounts of each by their* MOLECULAR WEIGHTS; then *find the simplest ratio in whole numbers for the numbers thus obtained.*

Example.—An analysis of bournonite from Wolfsberg gave C. Bromeis the results under (1) below. These percentages divided by the respective atomic weights, as indicated, give the numbers under (2). Finally the ratio of these numbers gives very nearly 1 : 3 : 1 : 1. Hence the formula derived is $CuPbSbS_3$. The theoretical values called for by the formula are added under (4).

	(1)	(2)	(3)	(4)
Sb	24·34 ÷ 120	= 0·203	1	24·7
S	19·76 ÷ 32	= 0·617	3	19·8
Pb	42·88 ÷ 206·4	= 0·208	1	42·5
Cu	13·06 ÷ 63·2	= 0·207	1	13·0
	100·04			100·0

Second Example.—The mean of two analyses of a garnet from Alaska gave Kountze the results under (1) below. Here as usual the percentage amounts of the several molecular groups (SiO_2, Al_2O_3, etc.) are given instead of those of the elements. These amounts divided by the respective molecular weights give the numbers under (2). In this case the amounts of the protoxides are taken together and the ratio thus obtained is 3·09 : 1 : 2·92, which corresponds approximately to the formula $3FeO.Al_2O_3.3SiO_2$, or $Fe_3Al_2(SiO_4)_3$. The magnesium in this garnet would ordinarily be explained by the presence of the pyrope molecule ($Mg_3Al_2[SiO_4]_3$) together with the simple almandite molecule whose composition is given above.

	(1)	(2)		(3)
SiO_2	39·29 + 60	= 0·655		3·09
Al_2O_3	21·70 + 102	= 0·212		1
Fe_2O_3	*tr.*			
FeO	30·82 ÷ 71·9	= 0·429	0·619	2·92
MnO	1·51 ÷ 70·8	= 0·022		
MgO	5·26 ÷ 40	= 0·132		
CaO	1·99 ÷ 55·9	= 0·036		
	100·57			

It is necessary, when very small quantities only of certain elements (as MnO, MgO, CaO above) are present to neglect them in the final formula, reckoning them in with the elements which they replace, that is, with those of the same quantivalence. The degree of correspondence between the analysis and the formula deduced, if the latter is correctly assumed, depends entirely upon the accuracy of the former.

456. Isomorphism.—Chemical compounds which have an analogous composition and a closely related crystalline form are said to be *isomorphous*. This phenomenon, called ISOMORPHISM, was first clearly brought out by Mitscherlich.

Many examples of groups of isomorphous compounds will be found among the minerals described in the following pages. Some examples are mentioned here in order to elucidate the subject.

In the brief discussion of the periodic classification of the chemical elements of Art. **439**, attention has been called to the prominent groups among the elements which form analogous compounds. Thus calcium, barium, and strontium, and also lead, form the two series of analogous compounds,

Aragonite Group.		Barite Group.
$CaCO_3$, aragonite.	Also	$CaSO_4$, anhydrite.
$BaCO_3$, witherite.		$BaSO_4$, barite.
$SrCO_3$, strontianite.		$SrSO_4$, celestite.
$PbCO_3$, cerussite.		$PbSO_4$, anglesite.

Further, the members of each series crystallize in closely similar forms. The carbonates are orthorhombic, with axial ratios not far from one another; thus the prismatic angle approximates to 60° and 120°, and corresponding to this they all exhibit pseudo-hexagonal forms due to twinning. The sulphates also form a similar orthorhombic series, and though anhydrite deviates somewhat widely, the others are close together in angle and in cleavage.

Again, calcium, magnesium, iron, zinc, and manganese form a series of carbonates with analogous composition, as shown in the list of the species of the *Calcite Group* given on p. 353. This table brings out clearly the close relation in form between the species named. Incidentally, as an example of the deviation in form sometimes observed, it is to be noticed that dolomite (and perhaps others) are not normally rhombohedral like calcite, but belong to the phenacite type (p. 80).

This table also illustrates another essential point in regard to an isomorphous series, viz., the presence of intermediate members, or *isomorphous mixtures* of the simple compounds. These are viewed by most authors as due to the presence of both molecules crystallized together, usually in a certain definite ratio. Thus in normal dolomite, ($CaCO_3$) and ($MgCO_3$) are both present in the ratio of 1 : 1, and its formula is $CaMg(CO_3)_2$ or $CaCO_3.MgCO_3$. In mesitite ($MgCO_3$) and ($FeCO_3$) are present in the ratio of 2 : 1; its formula is $Mg_2Fe(CO_3)_3$ or $2MgCO_3.FeCO_3$. If it is not desired to express the ratio of the elements present, it is convenient to write the elements together in a parenthesis separated by a comma. Thus $(Ca,Mg,Fe)CO_3$ would mean a carbonate in which calcium, magnesium, and iron are all present.

The *Apatite Group* forms another valuable illustration since in it are represented the analogous compounds, apatite and pyromorphite, both phosphates, but respectively phosphates of calcium and lead; also the analogous lead compounds pyromorphite, mimetite, and vanadinite respectively lead phosphate, lead arsenate, and lead vanadate. Further, in all these compounds the radical (RCl) or (RF) enters in the same way (see Art. 453). Thus the formulas for the two kinds of apatite and that for pyromorphite are as follows:

$$(CaF)Ca_4(PO_4)_3, \qquad (CaCl)Ca_4(PO_4)_3, \qquad (PbCl)Pb_4(PO_4)_3.$$

Some of the more important isomorphous groups are mentioned below. For a discussion of them, as well as of many others that might be mentioned here, reference must be made to the descriptive part of this work.

Isometric System.—The Spinel group, including spinel, $MgAl_2O_4$: also magnetite, chromite, franklinite, gahnite, etc. The Galena group, as galena, PbS; argentite, Ag_2S, etc. The Garnet group, as grossularite, $Ca_3Al_2Si_3O_{12}$, etc.

Tetragonal System.—Rutile group, including rutile, TiO_2; cassiterite, SnO_2. The Scheelite group, including scheelite, $CaWO_4$; stolzite, $PbWO_4$; wulfenite, $PbMoO_4$.

Hexagonal System.—Apatite group, already mentioned, including apatite, pyromorphite, mimetite, and vanadinite. Corundum group, corundum, Al_2O_3; hematite, Fe_2O_3.

Rhombohedral System.—Calcite group, already mentioned. Phenacite group, etc.

Orthorhombic System.—Aragonite group, and Barite group, both mentioned above. Chrysolite group, $(Mg,Fe)_2SiO_4$; Topaz group, etc.

Monoclinic System.—Copperas group, including melanterite, $FeSO_4 + 7$ aq; bieberite, $CoSO_4 + 7$ aq, etc. Pyroxene and Amphibole groups, and the Mica group.

Monoclinic and Triclinic Systems.—Feldspar group.

457. Isomorphous Mixtures.—It is important to note that the intermediate compounds in the case of an isomorphous series, such as those spoken of in the preceding article, often show a distinct gradation in crystalline form, and more particularly in physical characters (*e.g.*, specific gravity, optical properties, etc.) This is illustrated by the species of the calcite group already referred to; also still more strikingly by the group of the triclinic feldspars as fully discussed under the description of that group. See further Art. 406.

The feldspars also illustrate two other important points in the subject, which must be briefly alluded to here. The triclinic feldspars have been shown by Tschermak to be isomorphous mixtures of the end compounds in varying proportions:

$$\text{Albite, } NaAlSi_3O_8. \qquad \text{Anorthite, } CaAl_2Si_2O_8.$$

Here it is seen that these compounds have not an analogous composition in the narrow sense previously illustrated, and yet they are isomorphous and form an isomorphous series. Other examples of this are found among the pyroxenes, the scapolites, etc.

Further, the Feldspar group in the broader sense includes several other species, conspicuously the monoclinic orthoclase, $KAlSi_3O_8$, which, though belonging to a different system, still approximates closely in form to the triclinic species.

458. Dimorphism. Isodimorphism.—A chemical compound, which crystallizes in two forms genetically distinct, is said to be *dimorphous;* if in three, *trimorphous*, or in general *pleomorphous.* This phenomenon is called DIMORPHISM or PLEOMORPHISM.

An example is given by the compound calcium carbonate ($CaCO_3$), which is dimorphous: appearing as calcite and as aragonite. As *calcite* it crystallizes in the rhombohedral system, and, unlike as its many crystalline forms are, they may be all referred to the same fundamental rhombohedron, and, what is more, they have all the same cleavage and the same specific gravity (2·7), and, of course, the same optical characters. As *aragonite,* calcium carbonate appears in orthorhombic crystals, whose optical characters are entirely different from those of calcite; moreover, the specific gravity of aragonite (2·9) is higher than that of calcite (2·7).

Many other examples might be given: Silica (SiO_2) is dimorphous; appearing as *quartz,* rhombohedral, G. = 2·66; as *tridymite,* hexagonal, G. = 2 3, and perhaps in other forms. Titanium dioxide (TiO_2) is trimorphous, the species being called *rutile,* tetragonal ($\acute{c}$ = 0·6442), G. = 4·25; *octahedrite,* tetragonal ($\acute{c}$ = 1·778), G. = 3·9; and *brookite,* orthorhombic, G. = 4·15. Carbon appears in two forms, in diamond and graphite. Other familiar examples are pyrite and marcasite (FeS_2), sphalerite and wurtzite (ZnS), etc.

When two or more analogous compounds are at the same time isomorphous and dimorphous, they are said to be *isodimorphous,* and the phenomenon is called ISODIMORPHISM. An example of this is given in the Pyrite and Marcasite groups described later. Thus we have in the isometric Pyrite Group, pyrite, FeS_2, smaltite, $CoAs_2$; in the orthorhombic Marcasite Group, marcasite, FeS_2, safflorite, $CoAs_2$, etc.

459. Chemical and Microchemical Analysis.—The analysis of minerals is a subject treated of in chemical works, and need not be touched upon here except so far as to note the convenient use of certain qualitative methods, as described in the later part of this chapter.

Of more importance are the *microchemical* methods applicable to sections under the microscope and often yielding decisive results with little labor. This subject has been particularly developed by Bořicky, Haushofer, Behrens, Streng, and others. Reference is made to the discussion by Rosenbusch (Mikr. Phys., 1892, p. 259 *et seq.,* also the list of authors on p. 212.)

460. Mineral Synthesis.—The occurrence of certain mineral compounds (*e.g.,* the chrysolites) among the products of metallurgical furnaces has long been noted. But it has only been in recent years that the formation of artificial minerals has been made the subject of minute systematic experimental study. In this direction the French chemists have been particularly successful, and now it may be stated that the majority of common minerals—quartz, the feldspars, amphibole, mica, etc.—have been obtained in crystallized form. Even the diamond has been formed in minute crystals by Moissan. These studies are obviously of great importance particularly as throwing light upon the method of formation of minerals in nature (*e.g.,* the diamond). The chief results of the work thus far done are given in the volumes mentioned in the Introduction, p. 4.

461. Alteration of Minerals. Pseudomorphs.—The chemical alteration of mineral species under the action of natural agencies is a subject of great importance and interest, particularly when it results in the change of the original composition into some other equally definite compound. A crystallized mineral which has thus suffered change so that its form no longer belongs to its chemical composition has already been defined (Art. **252**, p. 144) as a *pseudomorph* It remains to describe more fully the different kinds of pseudomorphs. Pseudomorphs are classed under several heads:

1. Pseudomorphs by *substitution.*

2. Pseudomorphs by simple *deposition,* and either by (*a*) *incrustation* or (*b*) *infiltration.*

3. Pseudomorphs by *alteration;* and these may be altered
   (*a*) without a change of composition, by *paramorphism;*
   (*b*) by the loss of an ingredient;
   (*c*) by the assumption of a foreign substance;
   (*d*) by a partial exchange of constituents.

1. The first class of pseudomorphs, by *substitution,* embraces those cases where there has been a gradual removal of the original material and a corresponding and simultaneous replacement of it by another, without, however, any chemical reaction between the two. A common example of this is a piece of fossilized wood, where the original fiber has been replaced entirely by silica. The first step in the process was the filling of the pores and cavities by the silica in solution, and then as the woody fiber by gradual decomposition disappeared the silica further took its place. Other examples are quartz after fluorite, calcite, and many other species; cassiterite after orthoclase; native copper after aragonite, etc.

2. Pseudomorphs by *incrustation* form a less important class. Such are the crusts of quartz formed over fluorite. In most cases the removal of the original mineral has gone on simultaneously with the deposition of the second, so that the resulting pseudomorph is properly one of substitution. In pseudomorphs by *infiltration* a cavity made by the removal of a crystal has been filled by another mineral.

3. The third class of pseudomorphs, by *alteration,* includes a considerable proportion of the observed cases, of which the number is very large. Conclusive evidence of the change which has gone on is often furnished by a nucleus of the original mineral in the center of the altered crystal—*e.g.*, a kernel of cuprite in a pseudomorphous octahedron of malachite; also of chrysolite in a pseudomorphous crystal of serpentine, etc.

(*a*) An example of *paramorphism*—that is, of a change in molecular constitution without change of chemical substance—is furnished by the change of aragonite to calcite (both $CaCO_3$) at a certain temperature; also the *paramorphs* of rutile after brookite (both TiO_2) from Magnet Cove, Arkansas.

(*b*) An example of the pseudomorphs in which alteration is accompanied by a loss of ingredients is furnished by crystals of native copper in the form of cuprite.

(*c*) In the change of cuprite to malachite—*e.g.*, the familiar crystals from Chessy, France—an instance is afforded of the assumption of an ingredient—viz., carbon dioxide (and water). Pseudomorphs of gypsum after anhydrite occur where there has been an assumption of water alone.

(*d*) A partial exchange of constituents—in other words, a loss of one and gain of another—takes place in the change of feldspar to kaolin, in which the potash silicate disappears and water is taken up; pseudomorphs of limonite after pyrite or siderite, of chlorite after garnet, pyromorphite after galena, are other examples.

The chemical processes involved in such changes open a wide and important field for investigation. Their study has served to throw much light on the chemical constitution of mineral species and the conditions under which they have been formed. For the literature of the subject see the Introduction, p. 3 (Blum, Bischof, Roth, etc.). As typical studies of special cases the following articles are referred to:

Genth. Corundum, etc. Am. Phil. Soc. Philad., **13**, 361, 1873.
J. D. Dana. Serpentine pseudomorphs, Tilly Foster mine. Am. J. Sc., **8**, 371, 1874.
Brush and Dana. Spodumene, etc., Branchville, Ct. Am. J. Sc., **20**, 257, 1880.
Schrauf. Serpentine of Bohemia. Zs. Kryst., **6**, 321, 1882.

CHEMICAL EXAMINATION OF MINERALS.

462. The complete investigation of the chemical composition of a mineral includes, first, the identification of the elements present by qualitative analysis, and, second, the determination of the relative amounts of each by quantitative analysis, from which last the formula can be calculated. Both processes carried out in full call for the equipment of a chemical laboratory. An approximate qualitative analysis, however, can, in many cases, be made quickly and simply with few conveniences. The methods employed involve either (*a*) the use of acids or other reagents "in the wet way," or (*b*) the use of the blowpipe, or of both methods combined. Some practical instructions will be given applying to both cases.

EXAMINATION IN THE WET WAY.

463. Reagents, etc.—The most commonly employed chemical reagents are the three mineral acids, hydrochloric, nitric, and sulphuric acids. To these may be added ammonia, also solutions of barium chloride, silver nitrate, ammonium molybdate, ammonium oxalate; finally, distilled water in a wash-bottle.

A few test-tubes are needed for the trials and sometimes a porcelain dish with a handle called a casserole; further, a glass funnel and filter-paper. The Bunsen gas-burner (p. 256) is the best source of heat, though an alcohol lamp may take its place. It is unnecessary to remark that the use of acids and the other reagents requires much care to avoid injury to person or clothing.

In testing the powdered mineral with the acids, the important points to be noted are: (1) the degree of solubility, and (2) the phenomena attending entire or partial solution; that is, whether (*a*) a solution is obtained quietly, without effervescence, and, if so, what its color is; or (*b*) a gas is evolved, producing effervescence; or (*c*) an insoluble constituent is separated out.

464. Solubility.—In testing the degree of solubility hydrochloric acid is most commonly used, though in the case of many metallic minerals, as the sulphides and compounds of lead and silver, nitric acid is required. Less often sulphuric acid and aqua regia (nitro-hydrochloric acid) are resorted to.

The trial is usually made in a test-tube, and in general the fragment of mineral to be examined should be first carefully pulverized in an agate mortar. In most cases the heat of the Bunsen burner must be employed.

(*a*) Many minerals are completely *soluble without effervescence;* among these are some of the oxides, as hematite, limonite, göthite, etc.; some sulphates, many phosphates and arsenates, etc. Gold and platinum are soluble only in aqua regia or nitro-hydrochloric acid.

A yellow solution is usually obtained if much iron is present; a blue or greenish-blue solution (turning deep blue on the addition of ammonia in excess) from compounds of copper; pink or pale rose from cobalt, etc.

(*b*) *Solubility with effervescence* takes place when the mineral loses a gaseous ingredient, or when one is generated by the mutual reaction of acid and mineral. Most conspicuous here are the *carbonates,* all of which dissolve with effervescence, giving off the odorless gas *carbon dioxide* (CO_2), though some of them only when pulverized, or, again, on the addition of heat. In applying this test dilute hydrochloric acid is employed.

Sulphureted hydrogen, or hydrogen sulphide (H_2S), is evolved by some sulphides when dissolved in hydrochloric acid: this is true of sphalerite, stibnite, etc. This gas is readily recognized by its offensive odor.

Chlorine is evolved by oxides of manganese and also chromic and vanadic acid salts when dissolved in hydrochloric acid.

Nitrogen dioxide (NO_2) is given off, in the form of red suffocating fumes, by many metallic minerals, and also some of the lower oxides (cuprite, etc.), when treated with nitric acid.

(*c*) The *separation of an insoluble ingredient* takes place: With many silicates, the *silica* separating sometimes as a fine powder, and again as a jelly; in the latter case the mineral is said to *gelatinize* (sodalite, analcite). In order to test this point the finely pulverized silicate is digested with strong hydrochloric acid, and the solution afterward slowly evaporated nearly to dryness. With a considerable number of silicates the gelatinization takes place only after ignition; while some others, which ordinarily gelatinize, are rendered insoluble by ignition.

With many sulphides (as pyrite) a separation of *sulphur* takes place when they are treated with nitric acid.

Some compounds of titanium and tungsten are decomposed by hydrochloric acid with the separation of the oxides of the elements named (TiO_2, WO_3). The same is true of salts of molybdic and vanadic acids, only that here the oxides are soluble in an excess of the acid.

Compounds containing silver, lead, and mercury give with hydrochloric acid insoluble residues of the *chlorides*. These compounds are, however, soluble in nitric acid.

When compounds containing tin are treated with nitric acid, the *tin dioxide* (SnO_2) separates as a white powder. A corresponding reaction takes place under similar circumstances with minerals containing arsenic and antimony.

Insoluble Minerals.—A large number of minerals are not sensibly attacked by any of the acids. Among these may be named the following oxides: Corundum, spinel, chromite, diaspore, rutile, cassiterite, quartz; also cerargyrite; many silicates, titanates, tantalates, and niobates; some of the sulphates, as barite, celestite; many phosphates, as xenotime, lazulite, childrenite, amblygonite; also the borate, boracite.

465. Examination of the Solution.—If the mineral is difficultly, or only partially, soluble, the question as to solubility or insolubility is not always settled at once. Partial solution is often shown by the color given to the liquid, or more generally by the precipitate yielded, for example, on the addition of ammonia to the liquid filtered off from the remaining powder. The further examination of the solution yielded, whether from partial or complete solution, after the separation by filtration of any insoluble residue, requires the systematic laboratory methods of qualitative analysis.

It may be noted, however, that in the case of sulphates the presence of *sulphur* is shown by the precipitation of a heavy white powder of barium sulphate ($BaSO_4$) when barium chloride is added. The presence of *silver* in solution is shown by the separation of a white curdy precipitate of silver chloride (AgCl) upon the addition of any chlorine compound; conversely, the same precipitate shows the presence of *chlorine* when silver nitrate is added to the solution.

Again, *phosphorus* may be detected if present, even in small quantity, in a nitric acid solution of a mineral by the fine yellow powder which separates, sometimes after standing, when ammonium molybdate has been added.

EXAMINATION BY MEANS OF THE BLOWPIPE.*

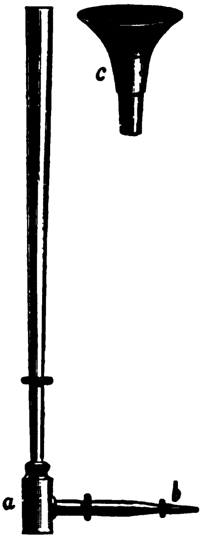
466. The use of the blowpipe, in skilled hands, gives a quick method of obtaining a partial knowledge of the qualitative composition of a mineral. The apparatus needed includes the following articles:

Blowpipe, lamp, platinum-pointed forceps, platinum wire, charcoal, glass tubes; also a small hammer with sharp edges, a steel anvil an inch or two long, a horseshoe magnet, a small agate mortar, a pair of cutting pliers, a three-cornered file.

Further, test-paper, both turmeric and blue litmus paper; a little pure tin-foil; also in small wooden boxes the fluxes: borax (sodium tetraborate), soda (anhydrous sodium carbonate), salt of phosphorus or microcosmic salt (sodium-ammonium phosphate), acid potassium sulphate ($HKSO_4$); also a solution of cobalt nitrate in a dropping bulb or bottle; further, the three acids mentioned in Art. **463**.

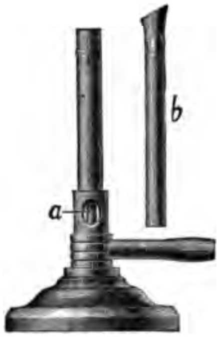
467. Blowpipe and Lamp.—A good form of *blowpipe* is shown in Fig. 570. The air-chamber, at *a*, is essential to stop the condensed moisture of the breath, but the tip (*b*), of platinum or of brass, though convenient is not essential, and many will prefer to do without the mouthpiece (*c*).

570.



The most convenient form of *lamp* is that furnished by an ordinary Bunsen gas-burner † (Fig. 571), provided with a tube, *b*, which when inserted cuts off the air-supply at *a*; the gas then burns at the top with the usual yellow flame. This flame should be one to one and a half inches high. The tip of the blowpipe is held near (or just within the flame, see beyond), and the air blown through it causes the flame to take the shape shown in Figs. 573, 574.

571.



It is necessary to learn to blow *continuously*, that is, to keep up a blast of air from the compressed reservoir in the mouth-cavity while respiration is maintained through the nose. To accomplish this successfully and at the same time to produce a clear flame without unnecessary fatiguing effort calls for some practice.

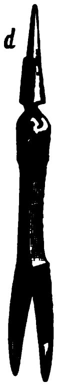
---

* The subject of the blowpipe and its use is treated very briefly in this place. The student who wishes to be fully informed not only in regard to the use of the various instruments, but also as to all the valuable reactions practically useful in the identification of minerals, should consult a manual on the subject. The Manual of Determinative Mineralogy, with an introduction on Blowpipe Analysis, by George J. Brush; revised and enlarged by Samuel L. Penfield (New York, 1896), is particularly to be recommended. Another recent work is the Manual of Qualitative Blowpipe Analysis and Determinative Mineralogy by F. M. Endlich (New York, 1892).

† Instead of this, a good stearin candle will answer, or an oil flame with flat wick.

When the tube, *b*, is removed, the gas burns with a colorless flame and is used for heating glass tubes, test-tubes, etc. An alcohol lamp will serve the same purpose.

572.



468. Forceps. Wire.—The *forceps* (Fig. 572) are made of steel, nickel-plated, and should have a spring strong enough to support firmly the small fragment of mineral between the platinum points at *d*. The steel points at the other end are used to pick up small pieces of minerals, but must not be inserted in the flame. Care must be taken not to injure the platinum by allowing it to come in contact with the fused mineral, especially if this contains antimony, arsenic, lead, etc.

The *platinum wire* required should be of the size designated No. 27. A piece of platinum-foil is often useful; also a small platinum spoon.

469. Charcoal.—The *charcoal* employed should not snap and should yield but little ash; the kinds made from basswood, pine or willow are best. It is most conveniently employed in rectangular pieces, say four inches long, an inch wide, and three-quarters of an inch in thickness. The surface must always be perfectly clean before each trial.

Instead of charcoal a support of the metal aluminium, as suggested by Ross, is used by some workers with good results.

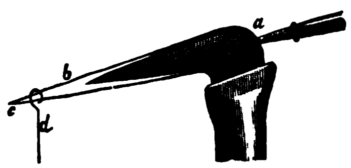
470. Glass Tubes.—The glass tubes should be of rather hard glass and say one-sixth to one-quarter of an inch in interior diameter. The smaller size is suitable for the *closed tubes;* these are simply made by heating a piece six inches long in the middle and then drawing the ends apart, the long ends being fused and pinched off. The larger size serves for *open tubes*, which may be five inches or so in length.

471. Blowpipe Flame.—The blowpipe flame, shown in Figs. 573, 574, consists of two cones: an inner of a blue color, and an outer cone which is nearly invisible. The heat is most intense just beyond the extremity of the blue flame, and the mineral is held at this point when its *fusibility* is to be tested.

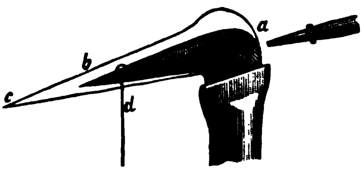
The outer cone is called the OXIDIZING FLAME (O.F.); it is characterized by the excess of the oxygen of the air over the carbon of the gas to be combined with it, and has hence an *oxidizing* effect upon the assay. This flame is best produced when the jet of the blowpipe is inserted a very little in the gas flame (see Fig. 573); it should be entirely non-luminous. The mineral is to be held at *d*.

The inner flame is called the REDUCING FLAME (R.F.); it is characterized by the excess of the carbon or hydrocarbons of the gas, which at the high temperature present tend to combine with the oxygen of the mineral brought into it (at *d*), or, in other words, *to reduce* it. The best reducing flame is produced when the blowpipe is held a little distance from the gas flame; it should retain the yellow color of the latter on its upper edge (see Fig. 574).

573.



574.



472. Methods of Examination.—The blowpipe investigation of minerals includes their examination, (1) in the platinum-pointed forceps, (2) in the closed and the open tubes, (3) on charcoal or other support, and (4) with the fluxes on the platinum wire.

1. EXAMINATION IN THE FORCEPS.

473. Use of the Forceps.—Platinum-pointed forceps are employed to hold the fragment of the mineral while a test is made as to its fusibility; also when the presence of a volatile ingredient which may give the flame a characteristic color is tested for, etc.

The following practical points must be regarded: (1) Metallic minerals, especially those containing arsenic or antimony, which when fused might injure the platinum, should first be examined on charcoal*; (2) the fragment taken should be thin, and as small as can conveniently be held, with its edge projecting well beyond the points; (3) when decrepitation takes place, the heat must be applied slowly, or, if this does not prevent it, the mineral may be powdered and a paste made with water, thick enough to be held in the forceps or on the platinum wire; or the paste may, with the same end in view, be heated on charcoal; (4) the fragment whose fusibility is to be tested must be held in the hottest part of the flame, just beyond the extremity of the blue cone.

474. Fusibility.—All grades of fusibility exist among minerals, from those which fuse in large fragments in the flame of the candle (stibnite, see below) to those which fuse only on the thinnest edges in the hottest blowpipe flame (bronzite); and still again there are a considerable number which are entirely infusible (*e.g.*, corundum).

The exact determination of the temperature of fusion is not easily accomplished (cf. Art. **413**, p. 232), and for purposes of determination of species it is unnecessary. The approximate *relative* degree of fusibility is readily fixed by referring the mineral to the following scale, suggested by von Kobell:

1. Stibnite.
2. Natrolite.
3. Almandite Garnet.
4. Actinolite.
5. Orthoclase.
6. Bronzite.

475. In connection with the trial of fusibility, the following phenomena may be observed: (*a*) *coloration* of the flame (see Art. **476**); (*b*) *swelling up* (stilbite), or *exfoliation* of the mineral (vermiculite); or (*c*) *glowing* without fusion (calcite); and (*d*) *intumescence*, or a spirting out of the mass as it fuses (scapolite).

The color of the mineral after ignition is to be noted; and the nature of the fused mass is also to be observed, whether a clear or blebby glass is obtained, or a black slag; also whether the bead or residue is magnetic or not (due to iron, less often nickel, cobalt), etc.

The ignited fragment, if nearly or quite infusible, may be moistened with the cobalt solution and again ignited, in which case, if it turns *blue*, this indicates the presence of aluminium (as with cyanite, topaz, etc.); but note that zinc silicate (calamine) also assumes a blue color. If it becomes *pink*, this indicates a compound of magnesium (as brucite).

Also, if not too fusible, it may, after treatment in the forceps, be placed upon a strip of moistened turmeric paper, in which case an *alkaline* reaction proves the presence of an alkali, sodium, potassium; or an alkaline earth, calcium, magnesium, barium, strontium.

---

* Arsenic, antimony, and easily reducible metals like lead, also copper, form more or less fusible alloys with platinum.

476. Flame Coloration.—The color often imparted to the outer blowpipe flame, while the mineral held in the forceps is being heated, makes possible the identification of a number of the elements.

The colors which may be produced, and the substances to whose presence they are due, are as follows:

Color.	Substance.
Carmine-red	Lithium.
Purple-red	Strontium.
Orange-red	Calcium.
Yellow	Sodium.
Yellowish green	Barium.
Siskine-green	Boron.
Emerald-green	Oxide of copper.
Bluish green	Phosphoric acid (phosphates).
Greenish blue	Antimony.
Whitish blue	Arsenic.
Azure-blue	Chloride of copper; also selenium.
Violet	Potassium.

A yellowish-green flame is also given by the oxide or sulphide of molybdenum; a bluish-green flame (in streaks) by zinc; a pale greenish flame by tellurium; a blue flame by lead.

477. **Notes.**—The presence of soda, even in small quantities, produces a yellow flame, which (except in the spectroscope) more or less completely masks the coloration of the flame due to other substances, *e.g.*, potassium. The use of a wedge of blue glass then allows the characteristic violet color to be observed. Silicates are often so difficultly decomposed that no distinct color is obtained even when the substance is present; in such cases (*e.g.*, potash feldspar) the powdered mineral may be fused on the platinum wire with an equal volume of gypsum, when the flame can be seen (at least through blue glass). Again, a silicate like tourmaline fused with a mixture of fluorite and acid potassium sulphate yields the characteristic green flame of boron. Phosphates and borates give the green flame in general best when they have been pulverized and moistened with sulphuric acid. Moistening with hydrochloric acid makes the coloration in many cases (as with the carbonates of calcium, barium, strontium) more distinct.

2. HEATING IN THE CLOSED AND OPEN TUBES.

478. The tubes are useful chiefly for examining minerals containing volatile ingredients, given off at the temperature of the gas flame.

In the case of the *closed tube*, the heating goes on practically uninfluenced by the air present, since this is driven out of the tube in the early stages of the process. In the *open tube*, on the other hand, a continual stream of hot air, that is, of hot oxygen, passes over the assay, tending to produce oxidation and hence often materially changing the result.

479. Closed Tube.—A small fragment is inserted, or a small amount of the powdered mineral—in this case with care not to soil the sides of the tube—and heat is applied by means of the ordinary Bunsen flame. The presence of a volatile ingredient is ordinarily shown by the deposit, or *sublimate*, upon the tube at some distance above the assay where the tube is relatively cool.

Independent of this, other phenomena may be noted, namely: *decrepitation*, as shown by fluorite, calcite, etc.; *glowing*, as exhibited by gadolinite; *phosphorescence*, of which fluorite is an example; *change of color* (limonite), and here the color of the mineral should be noted both when hot, and again after cooling; *fusion;* giving off *oxygen*, as mercuric oxide; yielding *acid* or *alkaline vapors*, which should be tested by inserting a strip of moistened litmus or turmeric paper in the tube.

Of the *sublimates* which form in the tube, the following are those with which it is most important to be familiar:

Substance.	Sublimate in the Closed Tube.
Water (H_2O)	Colorless liquid drops.
Sulphur (S)	Red to deep yellow, liquid; pale yellow, solid.
Tellurium dioxide (TeO_2)	Pale yellow to colorless, liquid; colorless or white, solid.
Arsenic sulphide (As_2S_3)	Dark red, liquid; reddish yellow, solid.
Antimony oxysulphide (Sb_2S_2O)	Black to reddish brown on cooling, solid.
Arsenic (As)	Black, brilliant metallic to gray crystalline, solid.
Mercury sulphide (HgS)	Deep black, red when rubbed very fine.
Mercury (Hg)	Gray metallic globules.

In addition to the above: Tellurium gives black fusible globules; selenium the same, but in part dark red when very small; the chloride of lead and oxides of arsenic and antimony give white solid sublimates.

480. Open Tube.—The small fragment is placed in the tube about an inch from the lower end, the tube being slightly inclined (say 20°), but not enough to cause the mineral to slip out, and heat applied beneath. The current of air passing upward through the tube during the heating process has an oxidizing effect. The special phenomena to be observed are the formation of a *sublimate* and the *odor* of the escaping gases. The acid or alkaline character of the vapors is tested for in the same way as with the closed tube. Fluorides, when heated in the open tube with previously fused salt of phosphorus, yield hydrofluoric acid, which gives an acid reaction with test-paper, has a peculiar pungent odor, and corrodes the glass.

The more important sublimates are as follows:

Substance.	Sublimate in the Open Tube.
Arsenic trioxide (As_2O_3)	White, crystalline, volatile.
Antimony antimonate (Sb_2O_4)	Straw-yellow, hot; white, cold. Infusible, non-volatile, amorphous. Obtained from stibnite, also the sulphantimonites (*e.g.*, bournonite) as dense white fumes. Usually accompanied by the following:
Antimony trioxide (Sb_2O_3)	White, crystalline, slowly volatile. From native antimony and compounds not containing sulphur.*
Tellurium dioxide (TeO_2)	White to pale yellow globules.
Selenium dioxide (SeO_2)	White, crystalline, volatile.
Molybdenum trioxide (MoO_3)	Pale yellow, hot; white, cold.
Mercury (Hg)	Gray metallic globules, easily united by rubbing.

It is also to be noted that if the heating process is too rapid for full oxidation, sublimates, like those of the closed tubes, may be formed, especially with sulphur (yellow), arsenic (black), arsenic sulphide (orange), mercury sulphide (black), antimony oxysulphide (black to reddish brown).

3. HEATING ON CHARCOAL.

481. The fragment (or powder) to be examined is placed near one end of the piece and this so held that the flame passes along its length; a slight ridge to prevent the mineral being blown off is sometimes useful. If the mineral decrepitates, it may be powdered, mixed with water, and then the material employed as a paste.

The reducing flame is employed if it is desired to *reduce* a metal (*e.g.*, silver, copper) from its ores: this is the common case. If, however, the mineral is to be *roasted*, that is, heated in contact with the air so as to oxidize and volatilize, for example, the sulphur, arsenic, antimony present, the oxidizing flame is needed and the mineral should be in powder and spread out.

---

* The distinction here made is important; cf. Penfield, revised edition of Brush's Determinative Mineralogy, 1896.

The points to be noted are as follows:

(*a*) The *odor* given off after short heating. In this way the presence of *sulphur*, *arsenic* (garlic or alliaceous odor), and *selenium* (odor of decayed horseradish) may be recognized.

(*b*) *Fusion.*—In the case of the salts of the alkalies the fused mass is absorbed into the charcoal; this is also true, after long heating, of the carbonates and sulphates of barium and strontium. (Art. 484.)

(*d*) *The Sublimate.*—By this means the presence of many of the metals may be determined. The color of the sublimate, both near the assay (N) and at a distance (D), as also when hot and when cold, is to be noted.

The important sublimates are the following:

Substance.	Sublimate on Charcoal.
Arsenic trioxide (As_2O_3)..........	White, very volatile, distant from the assay; also garlic fumes.
Antimony oxides (Sb_2O_3 and Sb_2O_4)	Dense white, volatile; forms near the assay.
Zinc oxide (ZnO).................	Canary-yellow, hot; white, cold: moistened with cobalt nitrate and ignited (O.F.) becomes green.
Molybdenum trioxide (MoO_3).......	Pale yellow, hot; yellow, cold; touched for a moment with the R.F. becomes azure-blue. Also a copper-red sublimate (MoO_2) near the assay.
Lead oxide (PbO).................	Dark yellow, hot; pale yellow, cold. Also (from sulphides) dense white (resembling antimony), a mixture of oxide, sulphite, and sulphate of lead.
Bismuth trioxide (Bi_2O_3)...........	Dark orange-yellow (N), paler on cooling; also bluish white (D). See further, p. 265.
Cadmium oxide (CdO)............	Nearly black to reddish brown (N) and orange yellow (D); often iridescent.

To the above are also to be added the following:

Selenium dioxide SeO_2, sublimate steel-gray (N) to white tinged with red (D); touched with R.F. gives an azure-blue flame; also an offensive selenium odor.

Tellurium dioxide, TeO_2, sublimate dense white (N) to gray (D); in R.F. volatilizes with green flame.

Tin dioxide, SnO_2, sublimate faint yellow hot to white cold; becomes bluish green when moistened with cobalt solution and ignited.

Silver (with lead and antimony), sublimate reddish.

(*e*) *The Infusible Residue.*—This may (1) glow brightly in the O.F., indicating the presence of calcium, strontium, magnesium, zirconium, zinc, or tin. (2) It may give an alkaline reaction after ignition: alkaline earths. (3) It may be magnetic, showing the presence of iron (or nickel). (4) It may yield a globule or mass of a metal (Art. 482).

482. Reduction on Charcoal.—In many cases the reducing flame alone suffices on charcoal to separate the metal from the volatile element present, with the result of giving a globule or metallic mass. Thus silver is obtained from argentite (Ag_2S) and cerargyrite (AgCl); copper from chalcocite (Cu_2S) and cuprite (Cu_2O), etc. The process of reduction is always facilitated by the use of soda as a flux, and this is in many cases (sulpharsenites, etc.) essential.

The finely pulverized mineral is intimately mixed with soda, and a drop of water added to form a paste. This is placed in a cavity in the charcoal, and subjected to a strong reducing flame. More soda is added as that present sinks into the coal, and, after the process has been continued some time, a metallic globule is often visible, or a number of them, which can be removed and separately examined. If not distinct, the remainder of the flux, the assay, and the surrounding coal are cut out with a knife, and the whole ground up in a mortar, with the addition of a little water. The charcoal is carefully washed away and the metallic globules, flattened out by the process, remain behind. Some metallic oxides are very readily reduced, as lead, while others, as copper and tin, require considerable skill and care.

The metals obtained (in globules or as a metallic mass) may be: *iron, nickel,* or *cobalt,* recognized by their being attracted by the magnet; *copper,* color red; *bismuth,* lead-gray, brittle; *gold,* yellow, not soluble in nitric acid; *silver,* white, soluble in nitric acid, the solution giving a silver chloride precipitate (p. 255); *tin,* white, harder than silver, soluble in nitric acid with separation of white powder (SnO_2); *lead,* lead-gray (oxidizing), soft and fusible. The coatings (see the list of sublimates above) often serve to identify the metal present.

The metals obtained may be also tested with borax on the platinum wire.

483. Detection of Sulphur in Sulphates.—By means of soda on charcoal the presence of sulphur in the sulphates may be shown, though they do not yield it upon simple heating. When soda is fused on charcoal with a compound of sulphur (sulphide or sulphate), sodium sulphide is formed, and if much sulphur is present the mass will have the *hepar* (liver-brown) color. In any case the presence of the sulphur is shown by placing the fused mass on a clean surface of silver, and adding a drop of water; a black or yellow stain of silver sulphide will be formed. Illuminating gas often contains sulphur, and hence, when it is used, the soda should be first tried alone on charcoal, and if a sulphur reaction is obtained (due to the gas), a candle or lamp must be employed in the place of the gas.

484. It is also useful in the case of many minerals to test their fusibility or infusibility with soda, generally on the platinum wire. Silica forms if not in excess a clear glass with soda, so also titanic acid. Salts of barium and strontium are fusible with soda, but the mass is absorbed by the coal. Many silicates, though alone difficultly fusible, dissolve in a little soda to a clear glass, but with more soda they form an infusible mass. Manganese, when present even in minute quantities, gives a bluish-green color to the soda bead.

4. TREATMENT ON THE PLATINUM WIRE.

485. Use of the Fluxes.—The three common fluxes are borax, salt of phosphorus, and carbonate of soda (p. 254). They are generally used with the platinum wire, less often on charcoal (see p. 260). If the wire is employed it must have a small loop at the end; this is heated to redness and dipped into the powdered flux, and the adhering particles fused to a bead; this operation is repeated until the loop is filled. Sometimes in the use of soda the wire may at first be moistened a little to cause it to adhere.

When the bead is ready it is, while hot, brought in contact with the powdered mineral, some of which will adhere to it, and then the heating process may be continued. Very little of the mineral is in general required, and the experiment should be commenced with a minute quantity and more added if necessary. The bead must be heated successively first in the oxidizing flame (O.F.) and then in the reducing flame (R.F.), and in each case the color noted when *hot* and when *cold.* The phenomena connected with fusion, if it takes place, must also be observed.

Minerals containing sulphur or arsenic, or both, must be first *roasted* (see p. 261) till these substances have been volatilized. If too much of the mineral has been added and the bead is hence too opaque to show the color, it may, while hot, be flattened out with the hammer, or drawn out into a wire, or part of it may be removed and the remainder diluted with more of the flux.

With salt of phosphorus, the wire should be held above the flame so that the escaping gases may support the bead; this is continued till quiet fusion is attained.

It is to be noted that the colors vary much with the amount of material present; they are also modified by the presence of other metals.

486. Borax.—The following list enumerates the different colored beads obtained with borax, both in the oxidizing (O.F.) and reducing flames (R.F.), and also the metals to the presence of whose oxides the colors are due. Compare further the reactions given in the list of elements (Art. **488**).

Color in Borax Bead.	Substance.
	1. Oxidizing Flame.
Colorless, or opaque white	Silica, calcium, aluminium; also silver, zinc, etc. Iron, cold—(pale yellow, hot, if in small amount).
Red, red-brown to brown	Chromium (CrO_3), hot—(yellowish green, cold). Manganese (Mn_2O_3), amethystine-red—(violet, hot). Iron (Fe_2O_3), hot—(yellow, cold)—if saturated. Nickel (NiO), red-brown to brown, cold—(violet, hot). Uranium (UO_3), hot—(yellow, cold).
Green	Copper (CuO), hot—(blue, cold, or bluish green if highly saturated). Chromium (CrO_3), yellowish green, cold—(red, hot).
Yellow	Iron (Fe_2O_3), hot—(pale yellow to colorless, cold)—but red-brown and yellow if saturated. Uranium (UO_3), hot, if in small amount; paler on cooling. Chromium (CrO_3), hot and in small amount—(yellowish green, cold).
Blue	Cobalt (CoO), hot and cold. Copper (CuO), cold if highly saturated—(green, hot).
Violet	Nickel (NiO), hot—(red-brown, cold). Manganese (Mn_2O_3), hot—(amethystine-red, cold).
	2. Reducing Flame (R.F.).
Colorless	Manganese (MnO), or a faint rose color.
Red	Copper (Cu_2O, with Cu), opaque red.
Green	Iron (FeO), bottle-green. Chromium (Cr_2O_3), emerald-green. Uranium (U_2O_3), yellowish green if saturated.
Blue	Cobalt (CoO), hot and cold.
Gray, turbid	Nickel (Ni).

487. Salt of Phosphorus.—This flux gives for the most part reactions similar to those obtained with borax. The only cases enumerated here are those which are distinct, and hence those where the flux is a good test.

With *silicates* this flux forms a glass in which the bases of the silicate are dissolved, but the silica itself is left insoluble. It appears as a skeleton readily seen floating about in the melted bead.

The colors of the beads, and the metals to whose oxides these are due, are:

Color.	Substance.
Red	Chromium in O.F., hot—(fine green when cold).
Green	Chromium in O.F. and R.F., when cold—(red in O.F., hot). Molybdenum in R.F., dirty green, hot; fine green, cold—(yellow-green in O.F.). Uranium in R.F., cold; yellow-green, hot. Vanadium, chrome-green in R.F., cold—(brownish red, hot). In O.F. dark yellow, hot, paler on cooling.

Color.	Substance.
Yellow..........	Molybdenum, yellowish green in O.F., hot, paler on cooling—(in R.F., dirty green, hot; fine green, cold). Uranium in O.F., hot; yellowish green, cold—(in R.F., yellowish green, hot; green, cold). Vanadium in O.F., dark yellow, hot, paler on cooling—(in R.F., brownish red, hot; chrome-green, cold).
Violet..........	Titanium (TiO_2) in R.F., yellow, hot. (Also in O.F. yellow, hot; colorless, cold.)

CHARACTERISTIC REACTIONS OF THE IMPORTANT ELEMENTS AND OF SOME OF THEIR COMPOUNDS.

488. The following list contains the most characteristic reactions, chiefly before the blowpipe and in some cases also in the wet way, of the different elements and their oxides. It is desirable for every student to gain familiarity with them by trial with as many minerals as possible. Many of them have already been briefly mentioned in the preceding pages. For a thoroughly full description of these and other characteristic tests (blowpipe and otherwise) reference should be made to the volume by Brush and Penfield referred to on p. 256.

It is to be remembered that while the reaction of a single substance may be perfectly distinct if alone, the presence of other substances may more or less entirely obscure these reactions; it is consequently obvious that in the actual examination of minerals precautions have to be taken, and special methods have to be devised, to overcome the difficulty arising from this cause. These will be gathered from the "pyrognostic characters" (Pyr.) given in connection with the description of each species in the Third Part of this work.

For many substances the most satisfactory and delicate tests are those which have been given by Bunsen in his important paper on Flame-reactions.* The methods, however, require for the most part so much detailed explanation, that it is only possible here to make this general reference to the subject.

Aluminium.—The presence of aluminium in most infusible minerals, containing a considerable amount, may be detected by the blue color which they assume when, after being heated, they are moistened with cobalt solution and again ignited (*e.g.*, cyanite, andalusite, etc.). Very hard minerals (as corundum) must be first finely pulverized. The test is not conclusive with fusible minerals since a glass colored blue by cobalt oxide may be formed. It is to be noted that the infusible calamine (zinc silicate) also assumes a blue color when treated with cobalt nitrate.

Antimony.—Antimonial minerals roasted on charcoal give dense white inodorous fumes; metallic antimony and its sulphur compounds give in the open tube a white sublimate of oxide of antimony (see p. 260). Antimony sulphide (stibnite), also many sulphantimonites, give in a strong heat in the closed tube a sublimate of antimony oxysulphide, black when hot, brown-red when cold. See also p. 260.

In nitric acid, compounds containing antimony deposit white insoluble metantimonic acid.

Arsenic.—Arsenides, sulpharsenites, etc., give off fumes when roasted on charcoal, usually easily recognized by their peculiar garlic odor. In the open tube they give a white, volatile, crystalline sublimate of arsenic trioxide. In the closed tube arsenic sulphide gives a sublimate dark brown-red when hot, and red or reddish yellow when cold; arsenic and some arsenides yield a black mirror of metallic arsenic in the closed tube. In arsenates the arsenic can be detected by the garlic odor yielded when a mixture of the powdered mineral with charcoal dust and sodium carbonate is heated (R F.) on charcoal.

Barium.—A yellowish-green coloration of the flame is given by all barium salts, except the silicates; an alkaline reaction is usually obtained after intense ignition.

---

* Flammenreactionen, Lieb. Ann., 138, 257, 1866, or Phil. Mag., 32, 81, 1866.

In solution the presence of barium is proved by the heavy white precipitate ($BaSO_4$) formed upon the addition of dilute sulphuric acid.

Bismuth.—On charcoal alone, or better with soda, bismuth gives a very characteristic orange-yellow sublimate; brittle globules of the reduced metal are also obtained (with soda). Also when treated with 3 or 4 times the volume of a mixture in equal parts of potassium iodide and sulphur, and fused on charcoal, a beautiful red sublimate of bismuth iodide is obtained; near the mineral the coating is yellow.

Boron.—Many compounds containing boron (borates, also the silicates datolite, danburite, etc.) tinge the flame intense yellowish green, especially if moistened with sulphuric acid. For some silicates (as tourmaline) the best method is to mix the powdered mineral with one part powdered fluorite and two parts potassium bisulphate. The mixture is moistened and placed on platinum wire. At the moment of fusion the green color appears, but lasts but a moment.

A dilute hydrochloric acid solution containing boron gives a reddish-brown color to turmeric paper which has been moistened with it and then dried at 100°; the color changes to black when ammonia is poured on the paper.

Calcium.—Many calcium minerals (carbonates, sulphates, etc.) give an alkaline reaction on turmeric paper after being ignited. A yellowish-red color is given to the flame by some compounds (*e.g.*, calcite after moistening with HCl); the strontium flame is a much deeper red.

In solutions (not too acid) calcium is precipitated as oxalate by the addition of ammonium oxalate.

Cadmium.—On charcoal with soda, compounds of cadmium give a characteristic sublimate of the reddish-brown oxide.

Carbonates.—All carbonates effervesce with *dilute* hydrochloric acid, yielding the odorless gas CO_2 (*e.g.*, calcite); many require to be pulverized, and some need the addition of heat (dolomite, siderite). Carbonates of lead should be tested with nitric acid.

Chlorides.—If a small portion of a mineral containing chlorine (a chloride, also pyromorphite, etc.) is added to the bead of salt of phosphorus, saturated with copper oxide, the bead when heated is instantly surrounded with an intense purplish flame of copper chloride.

In solution chlorine gives with silver nitrate a white curdy precipitate of silver chloride, which darkens in color on exposure to the light; it is insoluble in nitric acid, but entirely so in ammonia.

Chromium.—Chromium gives with borax a bead which (O.F.) is yellow to red (hot) and yellowish green (cold) and R.F. a fine emerald-green. With salt of phosphorus in O.F. the bead is dirty green (hot) and clear green (cold); in R.F. the same. Cf. Vanadium beyond (also p. 263).

Cobalt.—A beautiful blue bead is obtained with borax in both flames from minerals containing cobalt; the color may be obscured by considerable iron or nickel unless these are first oxidized off (p. 132). Where sulphur or arsenic is present the mineral should first be thoroughly roasted on charcoal.

Copper.—On charcoal, at least with soda, metallic copper can be reduced from most of its compounds. With borax it gives (O.F.) a green bead when hot, becoming blue when cold; also (R.F.), if saturated, an opaque red bead containing Cu_2O and often Cu is obtained.

Most metallic compounds are soluble in nitric acid. Ammonia produces a green precipitate in the solution, which is dissolved when an excess is added, the solution taking an intense blue color.

Fluorine.—Heated in the closed tube many fluorides give off fumes of hydrofluoric acid, which react acid with test-paper and etch the glass. Sometimes potassium bisulphate must be added (see also p. 260).

Heated gently in a platinum crucible with sulphuric acid, many compounds (*e.g.*, fluorite) give off hydrofluoric acid, which corrodes the exposed parts of a glass plate placed over it which has been coated with wax and then scratched.

Iron.—With borax iron gives a bead (O.F.) which is yellow to brownish red (according to quantity) while hot, but is colorless to yellow on cooling; R.F. becomes bottle-green (see p. 263). Minerals which contain even a small amount of iron yield a magnetic mass when heated in the reducing flame.

Lead.—With soda on charcoal a malleable globule of metallic lead is obtained from lead compounds; the coating has a yellow color near the assay; the sulphide gives also a white coating ($PbSO_3$) farther off (p. 261). On being touched with the reducing flame the coating disappears, tingeing the flame azure-blue.

In solutions dilute sulphuric acid gives a white precipitate of lead sulphate; when delicacy is required an excess of the acid is added, the solution evaporated to dryness, and water added; the lead sulphate, if present, will then be left as a residue.

Lithium.—Lithium gives an intense carmine-red to the outer flame, the color somewhat resembling that of the strontium flame but is deeper; in very small quantities it is evident in the spectroscope.

Magnesium.—Moistened, after heating, with cobalt nitrate and again ignited, a pink color is obtained from some infusible compounds of magnesium (*e.g.*, brucite).

Manganese.—With borax manganese gives a bead violet-red (O.F.), and colorless (R.F.). With soda (O.F.) it gives a bluish-green bead; this reaction is very delicate and may be relied upon, even in presence of almost any other metal.

Mercury.—In the closed tube a sublimate of metallic mercury is yielded when the mineral is heated with dry sodium carbonate. In the open tube the sulphide gives a mirror of metallic mercury; in the closed tube a black lusterless sublimate of HgS, red when rubbed, is obtained.

Molybdenum.—On charcoal molybdenum sulphide gives near the assay a copper-red stain (O.F.), and beyond a white coating of the oxide; the former becomes azure-blue when for a moment touched with the R.F. The salt of phosphorus bead (O.F.) is yellowish green (hot) and nearly colorless (cold); also (R.F.) a fine green.

Nickel.—With borax, nickel oxide gives a bead which (O.F.) is violet when hot and red-brown on cooling; (R.F.) the glass becomes gray and turbid from the separation of metallic nickel.

Niobium (Columbium).—An acid solution boiled with metallic tin gives a blue color. The reactions with the fluxes are not very satisfactory.

Nitrates.—These detonate when heated on charcoal. Heated in a tube with sulphuric acid they give off red fumes of nitrogen dioxide (NO_2).

Phosphorus.—Most phosphates impart a green color to the flame, especially after having been moistened with sulphuric acid, though this test may be rendered unsatisfactory by the presence of other coloring agents. If they are used in the closed tube with a fragment of metallic magnesium or sodium, and afterward moistened with water, phosphureted hydrogen is given off, recognizable by its disagreeable odor.

A few drops of a nitric acid solution, containing phosphoric acid, produces in a solution of ammonium molybdate a pulverulent yellow precipitate of ammonium phosphomolybdate.

Potassium.—Potash imparts a violet color to the flame when alone. It is best detected in small quantities, or when soda or lithia is present, by the aid of the spectroscope. See also p. 259.

Selenium.—On charcoal selenium fuses easily, giving off brown fumes with a peculiar disagreeable organic odor; the sublimate on charcoal is volatile, and when heated (R.F.) gives a fine azure-blue flame.

Silicon.—A small fragment of a silicate in the salt of phosphorus bead leaves a skeleton of silica, the bases being dissolved.

If a silicate in a fine powder is fused with sodium carbonate and the mass then dissolved in hydrochloric acid and evaporated to dryness, the silica is made insoluble, and when strong hydrochloric acid is added and then water, the bases are dissolved and the silica left behind.

Many silicates, especially those which are hydrous, are decomposed by strong hydrochloric acid, the silica separating as a powder or, after evaporation, as a jelly (see p. 255).

Silver.—On charcoal in O.F. silver gives a brown coating. A globule of metallic silver may generally be obtained by heating on charcoal in O.F., especially if soda is added. Under some circumstances it is desirable to have recourse to cupellation.

From a solution containing any salt of silver, the insoluble chloride is thrown down when hydrochloric acid is added. This precipitate is insoluble in acid or water, but entirely so in ammonia. It changes color on exposure to the light.

Strontium.—Compounds of strontium are usually recognized by the fine crimson-red which they give to the blowpipe flame; many yield an alkaline reaction after ignition. (Cf. barium.)

Sodium.—Compounds containing sodium in large amount give a strong yellow flame.

Sulphur, Sulphides, Sulphates.—In the closed tube some sulphides give off sulphur; in the open tube they yield sulphur dioxide, which has a characteristic odor and reddens a strip of moistened litmus paper. In small quantities, or in sulphates, sulphur is best detected by fusion on charcoal with soda. The fused mass, when sodium sulphide has thus been formed, is placed on a clean silver coin and moistened; a distinct black stain on the silver is thus obtained (the precaution mentioned on p. 262 must be exercised).

Manganese. Fuse with $NaCO_3$ on platinum l.a. Blue-green color. Dissolve fused material in warm water, add HNO_3. Pink color.

ite insoluble precipitate

or grayish sublimate, coating and color the

charcoal with soda or e malleable, but harder separates out.
a bead which is violet hydrochloric acid, and especially after partial

Titanium. Fuse mineral with potassium bisulphate in platinum dish. Dissolve fused mass in water, add a little H_2SO_4 until the material is all dissolved, & then add hydrogen peroxide. an [illegible]

f phosphorus bead (R.F.).
nc instead of tin, gives a

us bead (O.F.) a greenish 8).
(hot) changing to yellow-), fine green (cold). With ing from chromium); also

n is yellow while hot and in heated becomes a fine es blue when heated after

green. moistening with cobalt solution.

Zirconium.—A dilute hydrochloric acid solution, ng zirconium, imparts an orange-yellow color to turmeric paper, moistened by the solution.

DETERMINATIVE MINERALOGY.

488. Determinative Mineralogy may be properly considered under the general head of Chemical Mineralogy, since the determination of minerals depends mostly upon chemical tests. But crystallographic and all the physical characters have also to be used.

There is but one exhaustive way in which the identity of an unknown mineral may in all cases be fixed beyond question, and that is by the use of a complete set of determinative tables. By means of such tables the mineral in hand is referred successively from a general group into a more special one, until at last all other species have been eliminated, and the identity of the one given is beyond doubt.

A careful preliminary examination of the unknown mineral should, however, always be made before final recourse is had to the tables. This examination will often suffice to show what the mineral in hand is, and in any case it should not be omitted, since it is only in this way that a practical familiarity with the appearance and characters of minerals can be gained.

The student will naturally take note first of those characters which are at once obvious to the senses, that is: *crystalline form*, if distinct; *general structure, cleavage, fracture, luster, color* (and *streak*), *feel;* also, if the specimen is not too small, the apparent weight will suggest something as to the *specific gravity*. The characters named are of very unequal importance. Structure, if crystals are not present, and fracture are generally unessential except in distinguishing varieties; color and luster are essential with metallic, but generally very unimportant with unmetallic, minerals. *Streak* is of importance only with colored minerals and those of metallic luster (p. 187). Crystalline form and cleavage are of the highest importance, but may require careful study.

The first trial should be the determination of the *hardness* (for which end the pocket-knife is often sufficient in experienced hands). The second trial should be the determination of the *specific gravity*. Treatment of the powdered mineral with acids may come next; by this means (see pp. 254, 255) a carbonate is readily identified, and also other results obtained. Then should follow blowpipe trials, to ascertain the *fusibility*; the *color* given to the flame, if any; the character of the *sublimate* given off in the tubes and on charcoal; the metal reduced on the latter; the reactions with the *fluxes*, and other points as explained in the preceding pages.

How much the observer learns in the above way, in regard to the nature of his mineral, depends upon his knowledge of the characters of minerals in general, and upon his familiarity with the chemical behavior of the various elementary substances with reagents and before the blowpipe (pp. 264 to 267). If the results of such a preliminary examination are sufficiently definite to suggest that the mineral in hand is one of a small number of species, reference may be made to their full description in Part. IV. of this work for the final decision.

A number of tables, in which the minerals included are arranged according to their crystalline and physical characters, are added in the Appendix. They will in many cases aid the observer in reaching a conclusion in regard to a specimen in hand.

The first of these tables is intended to include all well-defined species, grouped according to the crystalline system to which they belong and arranged under each system in the order of their specific gravities; the hardness is also added in each case. The relative importance of the individual species is shown by the type employed. Following this are minor tables enumerating species characterized by some one of the prominent crystalline forms; that is, those crystallizing in cubes, octahedrons, rhombohedrons, etc. Other tables give the names of species prominent because of their cleavage; structure of different types; hardness; luster; the various colors, etc. The student is recommended to make frequent use of these tables, not simply for aid in the identification of specimens, but rather because they will help him in the difficult task of learning the prominent characters of the more important minerals.

PART IV. DESCRIPTIVE MINERALOGY.

489. Scope of Descriptive Mineralogy.—It is the province of Descriptive Mineralogy to describe each mineral species, as regards: (1) form and structure; (2) physical characters; (3) chemical composition and allied blowpipe characters; (4) occurrence in nature with reference to geographical distribution and association with other species; also in connection with the above to show how it is distinguished from other species. Further, to classify mineral species into more or less comprehensive groups according to those characters regarded as most essential. Other points which may or may not be included are the investigation of the methods of origin of minerals; the changes that they undergo in nature and the results of such alteration; also the methods by which the same compounds may be made in the laboratory; finally, the uses of minerals as ores, for ornament and in the arts.

490. Scheme of Classification.—The method of classification adopted in this work, and the one which can alone claim to be thoroughly scientific, is that which places similar chemical compounds together in a common class and which further arranges the mineral species into groups according to the more minute relations existing between them in chemical composition and in crystalline form and other physical properties.

Upon this basis there are recognized eight distinct classes, beginning with the Native Elements; these are enumerated on the following page. Under each of these, sections of different grades are made, also based on chemical relationships. Finally, the mineral species themselves are arranged, as far as possible, in isomorphous groups, including those which have, at once, analogous chemical composition and similar crystallization (see Art. **456**). It is unnecessary to take the space here to develop the entire scheme of classification in detail, since a survey of the successive sub-classes under any one of the divisions will make the principles followed entirely clear. A few remarks, only, are added for sake of illustration.

Under the Oxides, for example, the classification is as follows: First, the Oxides of silicon (quartz, tridymite, opal). Second, the Oxides of the semimetals, tellurium, arsenic, antimony, bismuth, also molybdenum, tungsten. Third, the Oxides of the metals, as copper, zinc, iron, manganese, tin, etc. The third section is then subdivided into the anhydrous and hydrous species. Further, the former fall into the four divisions: Protoxides, R_2O and RO; Sesquioxides, R_2O_3; Intermediate oxides, RO,R_2O_3; Dioxides, RO_2. Under each of these heads come finally the individual species, arranged so far as possible in isomorphous groups. Thus we have the Hematite group, the Rutile group, etc.

In regard to the various classes of salts it may be stated that, in general, they are separated into anhydrous, acid, basic and hydrous sections; the special subdivisions called for, however, vary in the different cases.

For an explanation of the abbreviations used in the description of species, see p. 4.

SCHEME OF CLASSIFICATION.

I. **Native Elements.**

II. **Sulphides, Selenides, Tellurides, Arsenides, Antimonides.**

III. **Sulpho-salts.—Sulpharsenites, Sulphantimonites, Sulphobismuthites.**

IV. **Haloids.—Chlorides, Bromides, Iodides; Fluorides.**

V. **Oxides.**

VI. **Oxygen Salts.**

1. **Carbonates.**
2. **Silicates, Titanates.**
3. **Niobates, Tantalates.**
4. **Phosphates, Arsenates, Vanadates; Antimonates. Nitrates.**
5. **Borates. Uranates.**
6. **Sulphates, Chromates, Tellurates.**
7. **Tungstates, Molybdates.**

VII. **Salts of Organic Acids:** Oxalates, Mellates, etc.

VIII. **Hydrocarbon Compounds.**

I. NATIVE ELEMENTS.

The NATIVE ELEMENTS are divided into the two distinct sections of the Metals and the Non-metals, and these are connected by the transition class of the Semi-metals. The distinction between them as regards physical characters and chemical relations has already been given (Art. **437**).

The only *non-metals* present among minerals are carbon, sulphur, and selenium; the last, in one of its allotropic forms, is closely related to the semi-metal tellurium.

The native *semi-metals* form a distinct group by themselves, since all crystallize in the rhombohedral system with a fundamental angle differing a few degrees only from 90°, as shown in the following list:

Tellurium, $rr' = 93° \; 3'$.	Arsenic, $rr' = 94° \; 54'$.
Antimony, $rr' = 92° \; 53'$.	Bismuth, $rr' = 92° \; 20'$.

An artificial form of selenium is known with metallic luster and rhombohedral in crystallization, with $rr' = 93°$. Zinc (also only artif.) is rhombohedral ($rr' = 93° \; 46'$) and connects the semi-metals to the true metals.

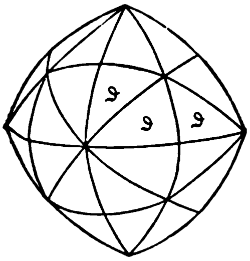
Among the *metals* the isometric GOLD GROUP is prominent, including gold, silver, copper, mercury, amalgam (AgHg), and lead.

Another related isometric group includes the metals platinum, iridium, palladium, and iron; further palladium is rhombohedral and also iridosmine (IrOs).

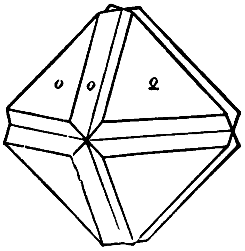
DIAMOND.

Isometric and probably tetrahedral, but the + and − forms not distinguished. Commonly in octahedrons, also hexoctahedrons and other forms; faces frequently rounded or striated and with triangular depressions (on *o*).

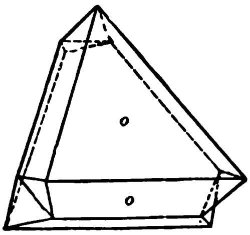
575.



576.



577.



Twins common with tw. pl. *o*. Crystals often distorted. In spherical forms; massive.

Cleavage: *o* highly perfect. Fracture conchoidal. Brittle. H. = 10. G. = 3·516–3·525 crystals. Luster adamantine to greasy. Color white or colorless; occasionally various pale shades of yellow, red, orange, green, blue, brown; sometimes black. Usually transparent; also translucent, opaque. Refractive and dispersive power high; index $n_y = 2{\cdot}4195$. (See Art. **305**.)

Var.—1. *Ordinary*. In crystals usually with rounded faces and varying from those which are colorless and free from flaws (*first water*) through many faint shades of color, yellow the most common; often full of flaws and hence of value only for cutting purposes.

2. *Bort* or *Boort;* rounded forms with rough exterior and radiated or confused crystalline structure.

3. *Carbonado* or *Carbon;* black diamond. Massive, crystalline, granular to compact, without cleavage. Color black or grayish black. Opaque. Obtained chiefly from Bahia, Brazil.

Comp.—Pure carbon; the variety carbonado yields on combustion a slight ash.

Pyr., **etc.**—Unaffected by heat except at very high temperatures, when (in an oxygen atmosphere) it burns to carbon dioxide (CO_2); out of contact with the air transformed into a kind of coke. Not acted upon by acids or alkalies.

Diff.—Distinguished (*e.g.*, from quartz crystal) by its extreme hardness and brilliant adamantine luster; the form, cleavage, and high specific gravity are also distinctive characters; it is optically isotropic; transparent to X-rays.

Obs.—The diamond occurs chiefly in alluvial deposits of gravel, sand, or clay, associated with quartz, gold, platinum, zircon, octahedrite, rutile, brookite, hematite, ilmenite, and also andalusite, chrysoberyl, topaz, corundum, tourmaline, garnet, etc.; the associated minerals being those common in granitic rocks or granitic veins. Also found in quartzose conglomerates, and further in connection with the laminated granular quartz rock or quartzose hydromica schist, *itacolumyte*, which in thin slabs is more or less flexible. This rock occurs at the mines of Brazil and the Urals; and also in Georgia and North Carolina, where a few diamonds have been found.

It has been reported as occurring *in situ* in a pegmatite vein in gneiss at Bellary in India. It occurs further in connection with an eruptive peridotite in South Africa. It has been noted as grayish particles forming one per cent of the meteorite which fell at Novo-Urei, Russia, Sept. 22, 1886; also in the form of black diamond (H. = 9) in the meteorite of Carcote, Chili; in the meteoric iron of Cañon Diablo, Arizona. It has been formed artificially by Moissan.

India was the chief source of diamonds from very early times down to the discovery of the Brazilian mines; the yield is now small. Of the localities, that in southern India, in the Madras presidency, included the famous "Golconda mines." The diamond deposits of Brazil have been worked since the early part of the 18th century, and have yielded very largely, although at the present time the amount obtained is small. The most important region was that near Diamantina in the province of Minas Geraes; also from Bahia, etc.

The discovery of diamonds in South Africa dates from 1867. They were first found in the gravel of the Vaal river; they occur from Potchefstroom down to the junction with the Orange river, and along the latter as far as Hope Town. These *river diggings* are now comparatively unproductive, and have been nearly abandoned for the *dry diggings*, discovered in 1871.

The latter are chiefly in Griqualand-West, south of the Vaal river, on the border of the Orange Free State. There are here a number of limited areas approximately spherical or oval in form, with an average diameter of some 200 to 300 yards, of which Kimberley, De Beer's, Du Toit's Pan and Bultfontein are the most important. A circle 3½ miles in diameter encloses the four principal diamond mines. The general structure is similar: a wall of nearly horizontal black carbonaceous shale with upturned edges enclosing the diamantiferous area. The upper portion of the deposit consists of a friable mass of little coherence of a pale yellow color, called the "yellow ground." Below the reach of atmospheric influences, the rock is more firm and of a bluish green or greenish color; it is called the "blue ground" or simply "the blue." This consists essentially of a serpentinous breccia: a base of hydrated magnesian silicate penetrated by calcite and opaline silica and enclosing fragments of bronzite, diallage, also garnet, magnetite, and ilmenite, and less commonly smaragdite, pyrite, zircon, etc. The diamonds are rather abundantly disseminated through the mass, in some claims to the amount of 4 to 6 carats per cubic yard. The original rock seems to have been a peculiar type of peridotite. These areas are believed to be volcanic pipes, and the occurrence of the diamonds is obviously connected with the eruptive outflow, they having probably been brought up from underlying rocks. The South African mines in Griqualand up to June 1896 are estimated to have yielded 60 million carats (13 tons) of diamonds, valued at about 370 million dollars.

Diamonds are also obtained in Borneo, associated with platinum, etc.; in Australia, and the Urals.

In the U. S. a few crystals have been met with in No. Carolina, Georgia, and Virginia; several have been found in Wisconsin, also in California at several points. Reported from Idaho and from Oregon with platinum.

Some of the famous diamonds of the world with their weights are as follows: the

Kohinoor, which weighed when brought to England 186 carats, and as recut as a brilliant, 106 carats; the Orlov, 193 carats; the Regent or Pitt, 137 carats; the Florentine or Grand Duke of Tuscany, 133 carats; the Sancy, 53 carats. The "Star of the South," found in Brazil in 1853, weighed before and after cutting respectively 254 and 125 carats. Also famous because of the rarity of their color are the green diamond of Dresden, 40 carats, and the deep blue Hope diamond from India, weighing 44 carats. The history of the above stones and of others is given in many works on gems.

South Africa has yielded some very large stones. Among these may be mentioned the following: The Victoria (or the Imperial) from one of the Kimberley mines weighed as found 457 carats; the Stewart weighed before and after cutting 288 and 120 carats respectively; the Tiffany diamond, of a brilliant golden yellow, weighs, cut as a double brilliant, 125 carats. The Excelsior from Jagersfontein weighed when found 971 carats and was 3 inches in its largest dimension; this is the largest ever known to have been discovered.

CLIFTONITE.—Carbon in minute cubic crystals. H. = 2·5. G. = 2·12. Color and streak black; from the Youndegin, West Australia, meteoric iron, found in 1884.

GRAPHITE. Plumbago. Black Lead.

Rhombohedral. In six-sided tabular crystals. Commonly in embedded foliated masses, also columnar or radiated; scaly or slaty; granular to compact; earthy.

Cleavage: basal, perfect. Thin laminæ flexible, inelastic. Feel greasy. H. = 1–2. G. = 2·09–2·23. Luster metallic, sometimes dull, earthy. Color iron-black to dark steel-gray. Opaque. A conductor of electricity.

Comp.—Carbon, like the diamond; often impure from the presence of iron sesquioxide, clay, etc.

Pyr., etc.—At a high temperature some graphite burns more easily than diamond, other varieties less so. B.B. infusible. Unaltered by acids.

Diff.—Characterized by its extreme softness (soapy feel)· iron-black color; metallic luster; low specific gravity; also by infusibility. Cf. molybdenite, p. 285.

Obs.—Graphite occurs in beds and embedded masses, laminæ, or scales in granite, gneiss, mica schist, crystalline limestone. It is in some places a result of the alteration by heat of coal. Often observed in meteoric irons. A common furnace product.

Occurs at Borrowdale in Cumberland; at Arendal in Norway, in quartz; in the Ural, Finland; Passau in Bavaria. In Irkutsk, in the Tunkinsk Mts., in eastern Siberia, the Alibert graphite mine affords some of the best graphite of the world. Large quantities are brought from the East Indies, especially from Ceylon.

Forms beds in gneiss, at Sturbridge, Mass.; at Ticonderoga, N. Y., with pyroxene and titanite; and at Hillsdale, Columbia Co., N. Y.; Byers, Chester Co., Pa.; Loudon Co., Va.; Wake Co., N. C. A graphitic earth is mined for paint in Arkansas. In California, in Alpine Co., Kern Co., etc. In Humboldt Co., Nevada; Beaver Co., Utah; Albany Co., Wyoming. A large deposit occurs at St. John, New Brunswick.

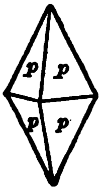
The name *black lead*, applied to this species, is inappropriate, as it contains no lead. The name graphite, of Werner, is derived from *γράφειν, to write*, alluding to its use for "lead" pencils.

SCHUNGITE. Amorphous carbon observed in some schists.

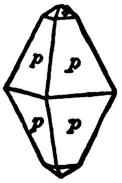
SULPHUR.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·8131 : 1 : 1·9034.

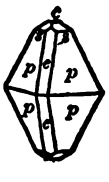
578.



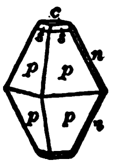
579.



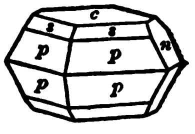
580.



581.

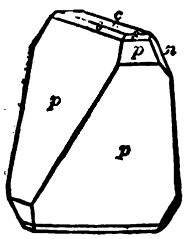


582.



Crystals commonly acute pyramidal; sometimes thick tabular ‖ *c*, also sphenoidal in habit (Fig. 583). See also Figs. 66, p. 30, and 302, p. 94. Also massive, in reniform shapes, incrusting, stalactitic and stalagmitic; in powder.

583.



mm''', $110 \wedge 1\bar{1}0 = 78° 14'$.
ce, $001 \wedge 101 = 66° 52'$.
cn, $001 \wedge 011 = 62° 17'$.
cs, $001 \wedge 113 = 45° 10'$.
cp, $001 \wedge 111 = 71° 40'$.
pp', $111 \wedge \bar{1}11 = 94° 52'$.
pp''', $111 \wedge 1\bar{1}1 = 73° 34'$.

Cleavage: *c*, *m*, *p* imperfect. Fracture conchoidal to uneven. Rather brittle to imperfectly sectile. H. = 1·5–2·5. G. = 2·05 – 2·09. Luster resinous. Color sulphur-yellow, straw- and honey-yellow, yellowish brown, greenish, reddish to yellowish gray. Streak white. Transparent to translucent. A non-conductor of electricity; by friction negatively electrified. Optically +. Double refraction strong. Ax. plane ‖ *b*. Bx ⊥ *c*. Dispersion $\rho < v$. $2H_{a.r} = 103° 18'$ Dx. Refractive indices, see p. 208.

Comp., Var.—Pure sulphur; often contaminated with clay, bitumen, and other impurities.

Sulphur may also be obtained in the laboratory in other allotropic forms; a monoclinic form is common.

Pyr., etc.—Melts at 108° C., and at 270° burns with a bluish flame yielding sulphur dioxide. Insoluble in water, and not acted on by the acids, but soluble in carbon disulphide.

Diff.—Readily distinguished by the color, fusibility and combustibility.

Obs.—The great repositories of sulphur are either beds of gypsum and the associate rocks, or the regions of active and extinct volcanoes. In the valley of Noto and Mazzaro, in Sicily; at Conil, in Spain; Bex, Switzerland; Cracow, Poland, it occurs in the former situation; near Bologna, Italy, in fine crystals, embedded in bitumen. Sicily and the neighboring volcanic isles; the Solfatara, near Naples; the volcanoes of the Pacific ocean, etc., are localities of the latter kind. It is also deposited from hot springs in Iceland; and is met with in certain metallic veins, thus with lead ores near Müsen and at Monte Poni, Sardinia. The Sicilian mines at Girgenti yield large quantities for commerce, including beautifully crystallized specimens.

Sulphur is found near the sulphur springs of New York, Virginia, etc., sparingly; in many coal deposits and elsewhere, where pyrites is undergoing decomposition; in minute crystals on cleavage surfaces of galena, Phenixville, Pa. Some important deposits occur in the western U. S., as in Wyoming, in the Uintah Mts., 30 miles s.e. of Evanston; in Nevada, Humboldt county; Steamboat Springs, Washoe Co.; Columbus, Esmeralda Co. In southern Utah in large deposits, at Cove Creek, Millard county. In California, at the geysers of Napa valley, Sonoma Co.; in Santa Barbara in good crystals; near Clear Lake, Lake Co., a large deposit. In the Yellowstone Park, in deposits and about the fumaroles.

Selensulphur. Contains sulphur and selenium, orange-red or reddish brown; from the islands Vulcano and Lipari.

ARSENIC.

Rhombohedral. Generally granular massive; sometimes reticulated, reniform, stalactitic.

Cleavage: *c* highly perfect. Fracture uneven and fine granular. Brittle. H. = 3·5. G. = 5·63–5·73. Luster nearly metallic. Color and streak tin-white, tarnishing to dark gray.

Comp.—Arsenic, often with some antimony, and traces of iron, silver, gold, or bismuth.

Pyr.—B.B. on charcoal volatilizes without fusing, coats the coal with white arsenic trioxide, and affords a garlic odor; the coating treated in R. F. volatilizes, tingeing the flame blue.

Obs.—Occurs in veins in crystalline rocks and the older schists, often accompanied by ores of antimony, ruby silver, realgar, sphalerite, and other metallic minerals. Thus in the silver mines of Saxony; also Andreasberg; Joachimsthal, Bohemia; in Hungary; Norway, etc. Abundant at Chañarçillo, Chili. In the U. S. sparingly at Haverhill and Jackson, N. H.; near Leadville, Colorado; Watson Creek, British Columbia.

Allemontite. Arsenical Antimony, $SbAs_3$. In reniform masses. G. = 6·203. Luster metallic. Color tin-white or reddish gray. From Allemont; Přibram, Bohemia, etc.

Tellurium. In prismatic crystals (Fig. 14, p. 10); commonly columnar to fine-granular massive. G. = 6·2. Color tin-white. From Transylvania and Colorado.

ANTIMONY.

Rhombohedral. Generally massive, lamellar and distinctly cleavable; also radiated; granular.

Cleavage: *c* highly perfect; also other cleavages. Fracture uneven; brittle. H. = 3–3·5. G. = 6·65–6·72. Luster metallic. Color and streak tin-white.

Comp.—Antimony, containing sometimes silver, iron, or arsenic.

Pyr.—B.B. on charcoal fuses, gives a white coating in both O. F. and R. F.; if the blowing be intermitted, the globule continues to glow, giving off white fumes, until it is finally crusted over with prismatic crystals of antimony trioxide. The white coating tinges the R. F. bluish green. Crystallizes readily from fusion.

Obs.—Occurs near Sala in Sweden; Andreasberg in the Harz; Allemont, Dauphiné; Přibram, Bohemia; Mexico; Chili; Borneo. In the U. S., at Warren, N. J., rare; in Kern Co., Cal. At Prince William parish, York Co., N. Brunswick.

BISMUTH.

Rhombohedral. Usually reticulated, arborescent; foliated or granular.

Cleavage: *c* perfect. Sectile. Brittle, but when heated somewhat malleable. H. = 2–2·5. G. = 9·70–9·83. Luster metallic. Streak and color silver-white, with a reddish hue; subject to tarnish. Opaque.

Comp., Var.—Bismuth, with traces of arsenic, sulphur, tellurium, etc.

Pyr., etc.—B.B. on charcoal fuses and entirely volatilizes, giving a coating orange-yellow while hot, lemon-yellow on cooling. Fuses at 265° C. Dissolves in nitric acid; subsequent dilution causes a white precipitate. Crystallizes readily from fusion.

Obs.—Occurs in veins in gneiss and other crystalline rocks and clay slate, accompanying various ores of silver, cobalt, lead and zinc. Thus at the mines of Saxony and Bohemia, etc.; Meymac, Corrèze, France. Also at Modum, Norway; at Falun, Sweden. In Cornwall and Devonshire; near Copiapo, Chili; Bolivia.

Occurs at Monroe, Conn.; Brewer's mine, Chesterfield district, S. Car.; near Cummins City, and elsewhere in Colorado.

Zinc. Probably does not occur in the native state. In the laboratory it is obtained in hexagonal prisms with tapering pyramids; also in complex crystalline aggregates. It also appears to crystallize in the isometric system, at least in various alloys.

Gold Group.

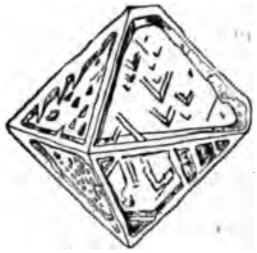
GOLD.

Isometric. Distinct crystals rare, *o* most common, also *d* (110), *m* (331), and *x* (18·10·1); crystals often elongated in direction of an octahedral axis, giving rise to rhombohedral forms (Figs. 452, 453, p. 135), and arborescent shapes; also in plates flattened ‖ *o*, and branching at 60° parallel either to the edges or diagonals of an *o* face (see pp. 131, 132). Twins: tw. plane *o*. Skeleton crystals common; edges salient or rounded; in filiform, reticulated, dendritic shapes. Also massive and in thin laminæ; often in flattened grains or scales.

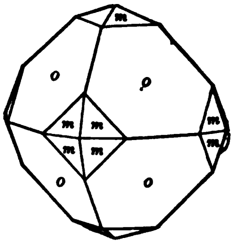
Cleavage none. Fracture hackly. Very malleable and ductile. H. = 2·5–3. G. = 15·6–19·3, 19·33 when pure. Luster metallic. Color and streak gold-yellow, sometimes inclining to silver-white and rarely to orange-red. Opaque.

Comp., Var.—Gold, but usually alloyed with silver in varying amounts and sometimes containing also traces of copper or iron.

584

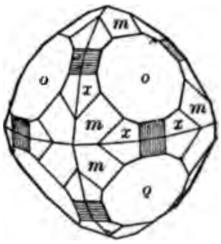


585.



$m = (311)$

586.



$x = (18 \cdot 10 \cdot 1)$

Var.—1. *Ordinary*. Containing up to 16 p. c. of silver. Color varying accordingly from deep gold-yellow to pale yellow, and specific gravity from 19·3 to 15·5. The ratio of gold to silver of 3 : 1 corresponds to 15·1 p. c. silver. For G. = 17·6, Ag = 9 p. c.; G. = 16·9, Ag = 13·2; G. = 14·6, Ag = 38·4, Rose. The purest gold which has been described is that from Mount Morgan, in Queensland, which has yielded 99·7 to 99·8 of gold, the remainder being copper with a little iron; silver is present only as a minute trace.

2. *Argentiferous; Electrum*. Color pale yellow to yellowish white; G. = 15·5–12·5. Ratio for the gold and silver of 1 : 1 corresponds to 36 p. c. of silver; 1½ : 1, to 26 p. c.; 2 : 1, to 21 p. c.; 2½ : 1, to 18 p. c. The word in Greek means also *amber;* and its use for this alloy probably arose from the pale yellow color it has as compared with gold.

Varieties have also been described containing palladium to 10 p. c. (*porpezite*), from Porpez, Brazil; bismuth, including the black gold of Australia (*maldonite*, Ulrich); also rhodium(?).

Pyr., etc.—B.B. fuses easily (at 1100° C.). Not acted on by fluxes. Insoluble in any single acid; soluble in nitro-hydrochloric acid (aqua regia), the separation not complete if more than 20 p. c. Ag is present.

Diff.—Readily recognized (*e g.*, from other metallic minerals, also from scales of yellow mica) by its malleability and high specific gravity, which last makes it possible to separate it from the gangue by washing; distinguished from chalcopyrite and pyrite by insolubility in nitric acid, both of which are brittle.

Observations.—Native gold is found, when *in situ*, with comparatively small exceptions, in the quartz veins that intersect metamorphic rocks, and to some extent in the wall rock of these veins. The metamorphic rocks thus intersected are mostly chloritic, talcose, and argillaceous schist of dull green, dark gray, and other colors; also, much less commonly, mica and hornblendic schist, gneiss, diorite, porphyry; and still more rarely, granite. A laminated quartzite, called itacolumite, is common in many gold regions, as those of Brazil and North Carolina, and sometimes specular schists, or slaty rocks containing much foliated specular iron (hematite) or magnetite in grains. A quartzose conglomerate is sometimes richly auriferous as in Transvaal. Less frequently calcite is the vein material.

The gold occurs in the quartz, irregularly distributed, in strings, scales, plates, and in masses which are sometimes an agglomeration of crystals; and the scales are often invisible to the naked eye. The associated minerals are: pyrite, which far exceeds in quantity all others, and is generally *auriferous;* next, chalcopyrite, galena, sphalerite, arsenopyrite, each frequently auriferous; often tetradymite and other tellurium ores, native bismuth, native arsenic, stibnite, cinnabar, magnetite, hematite; sometimes barite, scheelite, apatite, fluorite, siderite, chrysocolla. The quartz at the surface, or in the upper part of a vein, is usually cellular and rusted from the more or less complete disappearance of the pyrite and other sulphides by decomposition; but below, it is commonly solid.

The gold of the world was early gathered, not directly from the quartz veins (the "quartz reefs" of Australia and Africa), but from the gravel or sands of rivers or valleys in auriferous regions, or the slopes of mountains or hills, whose rocks contain in some part, and generally not far distant, auriferous veins; in California this method of hydraulic mining (*placer diggings*) has been carried on on a stupendous scale. Most of the gold of the Urals, Brazil, Australia, and all other gold regions has come from such alluvial washings. At the present time, however, the alluvial washings are much less depended upon, in many regions all the gold being obtained direct from the rock.

The alluvial gold is usually in flattened scales of different degrees of fineness, the size depending partly on the original condition in the quartz veins, and partly on the distance to which it has been transported and assorted by running water. The rolled masses when of some size are called *nuggets;* in rare cases these occur very large and of great value. The Australian gold region has yielded many large nuggets; one of these found in 1858 weighed 184 pounds, and another (1869) weighed 190 pounds. In the auriferous sands, crystals of zircon are very common; also garnet and cyanite in grains; often also monazite, diamond, topaz, corundum, iridosmine, platinum. The zircons are sometimes mistaken for diamonds.

Besides the free gold of the quartz veins and gravels, much gold is also obtained from auriferous sulphides or the oxides produced by their alteration, especially pyrite, also arsenopyrite, chalcopyrite, sphalerite, marcasite, etc. The only minerals containing gold in combination are the rare tellurides (sylvanite, etc.).

Gold exists more or less abundantly over all the continents in most of the regions of crystalline rocks, especially those of the semi-crystalline schists; and also in some of the large islands of the world where such rocks exist. In Europe, it occurs with silver ores in Hungary; in Transylvania at Verespatak and Nagyág; in the sands of the Rhine, the Danube, and other rivers; on the southern slope of the Pennine Alps; in Piedmont; in many of the streams of Cornwall; in North Wales; in Scotland, near Leadhills; in the county of Wicklow, Ireland; in Sweden, at Edelfors; in Norway, at Kongsberg.

In Asia, gold occurs along the eastern flanks of the Urals for 500 miles, and is especially abundant at the Berezov mines near Ekaterinburg; also at Petropavlovski; Nizhni Tagilsk; Miask, near Zlatoust and Mt. Ilmen, etc. Ekaterinburg is the capital of the mining district. Siberian mines less extensive occur in the lesser Altai; at Nerchinsk, east of L. Baikal, including the Kara mines. Asiatic mines occur also in Little Thibet, Ceylon, and Malacca, China especially in the Amur district, Corea, Japan, Formosa, Sumatra, Java, Borneo, the Philippines, and other East India Islands; at numerous points in British India.

In Africa, gold occurs at Kordofan, between Darfur and Abyssinia; also, south of the Sahara in western Africa, from the Senegal to Cape Palmas. Also in Transvaal in southern Africa, at Lydenburg, both quartz veins and alluvial washings, and at Eersteling; recently the Kaap gold fields in southeastern Transvaal have become very productive: the chief town of the region is Barberton. The quartz reefs of Witwatersrand in the immediate vicinity of Johannesburg, farther west, are also very productive; here the gold occurs largely in a quartzose conglomerate.

In South America, gold is found in Brazil; in the U. S. of Colombia; Chili; Bolivia; sparingly in Peru. Also in Central America, especially in Honduras; also San Salvador, Guatemala, Costa Rica.

In Australia, the principal gold mines occur along the streams in the mountains of New South Wales and along the continuation of the same range in Victoria. Also obtained largely in Queensland, N. Australia, particularly at Mt. Morgan, Rockhampton district. Also occurs in Tasmania, New Zealand, and New Caledonia.

In North America, there are numberless mines along the mountains of western America, and others along the eastern range of the Appalachians from Alabama and Georgia to Labrador, besides some in portions of the intermediate Archean region about Lake Superior. They occur at many points along the higher regions of the Rocky Mountains, in Mexico; in New Mexico, near Santa Fé, Cerillos, Avo, etc.; in Arizona, in the San Francisco, Wauba, Yuma, and other districts; in Colorado, abundant, the gold largely in auriferous pyrites, also in connection with tellurium minerals; the Cripple Creek region in Colorado affords at present large quantities of gold; also in Montana; the Black Hills of Dakota: Idaho especially the Cœur d'Alêne district, also Utah. Along ranges between the summit and the Sierra Nevada, in the Humboldt region and elsewhere. Also in the Sierra Nevada, mostly on its western slope (the mines of the eastern being principally silver mines). The auriferous belt may be said to begin in the Californian peninsula. Near the Tejon pass it enters California, and beyond for 180 miles it is sparingly auriferous, the slate rocks being of small breadth; but beyond this, northward, the slates increase in extent, and the mines in number and productiveness, and they continue thus for 200 miles or more. Gold occurs also in the Coast ranges in many localities, but mostly in too small quantities to be profitably worked. The regions to the north in Oregon and in Washington and Alaska, with British Columbia, are at many points auriferous, and productively so, though to a less extent than California. The Cariboo region on the Fraser river, and the Cassiar district on the Stickeen, have yielded considerable amounts. The Alaska quartz mines have been worked to some advantage, as also the gravels of the Yukon river and its tributaries; of the latter, the Klondike is now (1898) reputed to be fabulously rich.

In eastern North America, the chief mines are mostly confined to the States of Virginia, North and South Carolina, and Georgia, or along a line from the Rappahannock to the Coosa in Alabama. In Canada, gold occurs to the south of the St. Lawrence, in the soil on the Chaudière and elsewhere; in Nova Scotia, at Deloro, near Hastings, Ontario (in arsenopyrite); also in the Port Arthur region, north of Lake Superior, and in the river-gravels of the Pacific slope, as before noted.

The world's production of gold was in 1897 about $250,000,000, having considerably more than doubled since 1890. Of this amount the United States afforded about $61,500,000, Africa about $58,000,000, Australia nearly $56,000,000, Russia about $28,700,000, and other countries (China, Canada, India, So. America, etc.) the remainder. It is also interesting to note that in 1897 the production was nearly the same for the States of California and Colorado, the former $17,000,000, the latter a little in excess of this amount. In 1890 Colorado produced only a little more than $4,000,000.

SILVER.

Isometric. Crystals commonly distorted, in acicular forms, reticulated or arborescent shapes; coarse to fine filiform; also massive, in plates or flattened scales.

Cleavage none. Ductile and malleable. Fracture hackly. H. = 2·5–3. G. = 10·1–11·1, pure 10·5. Luster metallic. Color and streak silver-white, often gray to black by tarnish.

Comp., Var.—Silver, with some gold (up to 10 p. c.), copper, and sometimes platinum, antimony, bismuth, mercury.

Pyr., etc.—B.B. on charcoal fuses easily to a silver-white globule, which in O.F. gives a faint dark-red coating of silver oxide; crystallizes on cooling; fusibility about 1050° C. Soluble in nitric acid, and deposited again by a plate of copper. Precipitated from its solutions by hydrochloric acid in white curdy forms of silver chloride.

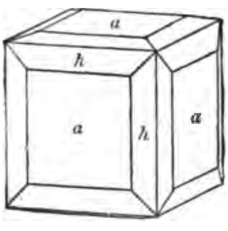
Diff.—Distinguished by its malleability, color (on the fresh surface), and specific gravity.

Obs.—Native silver occurs in masses, or in arborescent and filiform shapes, in veins traversing gneiss, schist, porphyry, and other rocks. Also occurs disseminated, but usually invisibly, in native copper, galena, chalcocite, etc.; rarely in volcanic ashes (Mallet).

The mines of Kongsberg, in Norway, have afforded magnificent specimens; also the Saxon mines; occurs in Bohemia at Přibram and Joachimsthal; at Andreasberg; Hungary; Allemont, Dauphiné; in the Ural near Berezov; in the Altai, at Zmeov; and in some of the Cornish mines. In Durango, Sinaloa, and Sonora, in Mexico, are noted mines affording native silver; abundant in Peru.

In the United States disseminated through much of the copper of Michigan; at Silver Islet and at Port Arthur, Lake Superior. Occurs in Idaho, at the "Poor Man's lode"; in Nevada, rare; in California, sparingly; in Silver Mountain district, Alpine Co.; in the Maris vein, in Los Angeles Co. In Colorado, at many localities, especially with argentiferous ores; in Montana, near Butte, Silver Bow Co., with manganese ores. In Arizona, at the Silver King mine, and with argentiferous ores elsewhere.

587.



h = (410)

COPPER.

Isometric. The tetrahexahedron the most common form (Fig. 587); also in octahedral plates. Crystals often irregularly distorted and passing into twisted and wire-like forms; filiform and arborescent. Massive; as sand. Twins: tw. pl. *o*, very common, often flattened or elongated to spear-shaped forms. Cf. pp. 131, 132.

Cleavage none. Fracture hackly. Highly ductile and malleable. H. = 2·5–3. G. = 8·8–8·9. Luster metallic. Color copper-red. Streak metallic shining. Opaque. An excellent conductor for heat and electricity.

Comp.—Pure copper; often containing some silver, bismuth, mercury, etc.

Pyr., etc.—B.B. fuses readily; on cooling becomes covered with a coating of black oxide. Dissolves readily in nitric acid, giving off red nitrous fumes, and produces a deep azure-blue solution with ammonia. Fusibility 780° C.

Obs.—Copper occurs in beds and veins accompanying its various ores, especially cuprite, malachite, and azurite; also with the sulphides, chalcopyrite, chalcocite, etc.; often abundant in the vicinity of dikes of igneous rocks; also in clay slate and sandstone.

Occurs at Turinsk, in the Ural, in fine crystals; at Nizhni Tagilsk and elsewhere; Siberia. In Germany, at the Friedrichssegen mine, Nassau. Common in Cornwall. Brazil, Chili, Bolivia, and Peru afford native copper. In South Australia abundant at Wallaroo; in New South Wales.

Occurs native throughout the red sandstone region of the eastern United States, sparingly in Massachusetts, Connecticut, and more abundantly in New Jersey. Near New Haven, Conn., a mass was found in the drift weighing nearly 200 pounds; smaller isolated masses have also been found. The Lake Superior copper region, near Keweenaw Point, in northern Michigan, is the most important locality in the world. The copper is obtained practically all in the native state, sometimes in immense masses, and is obtained over an area 200 miles in length. It occurs in both amygdaloidal dolerite and sandstone, near the junction of these two rocks; associated with calcite, prehnite, datolite, analcite, etc.; also distributed widely in grains through the sandstone. Occurs sparingly in California. In Arizona, common at the Copper Queen mine, Cochise Co.; also in Grant Co., N. Mexico, at the Santa Rita and other mines.

MERCURY. Quicksilver. Gediegen Quecksilber *Germ.*

In small fluid globules scattered through its gangue. G. = 13·596. Luster metallic, brilliant. Color tin-white. Opaque.

Comp.—Pure mercury (Hg); with sometimes a little silver.

Pyr., etc.—B.B. entirely volatile, vaporizing at 350° C. Becomes solid at −40° C., crystallizing in regular octahedrons with cubic cleavage; G. = 14·4. Dissolves in nitric acid.

Obs.—Mercury in the metallic state is a rare mineral, and is usually associated with the sulphide cinnabar, from which the supply of commerce is obtained. The rocks affording the metal and its ores are chiefly clay shales or schists of different geological ages. Also found in connection with hot springs. See cinnabar.

LEAD.

Isometric. Crystals rare. Usually in thin plates and small globular masses. Very malleable, and somewhat ductile. H. = 1·5. G. = 11·37, Harstig mine. Luster metallic. Color lead-gray. Opaque.

Comp.—Nearly pure lead; sometimes contains a little silver, also antimony.

Pyr.—B.B. fuses easily, coating the charcoal with a yellow oxide which, treated in R.F., volatilizes, giving an azure-blue tinge to the flame. Fusibility 330° C. Dissolves easily in dilute nitric acid.

Obs.—Of rare occurrence. Found at Pajsberg, Harstig, and Långban in Sweden; similarly at Nordmark; also in the gold washings of the Ural; reported elsewhere, but localities often doubtful. In the U. S., occurs at Breckinridge and Gunnison, Colorado; Wood River district, Idaho.

AMALGAM.

Isometric. Common habit dodecahedral. Crystals often highly modified (Fig. 100, p. 39). Also massive in plates, coatings, and embedded grains.

Cleavage: *d* in traces. Fracture conchoidal, uneven. Rather brittle to malleable. H. = 3–3·5. G. = 13·75–14·1. Luster metallic, brilliant. Color and streak silver-white. Opaque.

Comp.—(Ag,Hg), silver and mercury, varying from Ag_2Hg_3 to $Ag_{36}Hg$.

Var.—*Ordinary amalgam*, Ag_2Hg_3 (silver 26·4 p. c.) or AgHg (silver 35·0): also Ag_6Hg_3, etc. *Arquerite.* $Ag_{12}Hg$ (silver 86·6); G. = 10·8; malleable and soft. *Kongsbergite*, $Ag_{32}Hg$ or $Ag_{36}Hg$.

Pyr., etc.—B.B. on charcoal the mercury volatilizes and a globule of silver is left In the closed tube the mercury sublimes and condenses on the cold part of the tube in minute globules. Dissolves in nitric acid. Rubbed on copper it gives a silvery luster.

Obs.—From the Palatinate at Moschellandsberg; at Friedrichssegen, Nassau; from

Sala, Sweden; Kongsberg, Norway; Allemont, Dauphiné; Almaden, Spain; Chili; Vitalle Creek, Br. Columbia (*arquerite*).

Tin. Native tin has been reported from several localities. The only occurrence fairly above doubt is that from the washings at the headquarters of the Clarence river, near Oban, New South Wales. It has been found here in grayish-white rounded grains, with platinum, iridosmine, gold, cassiterite, and corundum.

Platinum-Iron Group.

PLATINUM.

Isometric. Crystals rare; usually in grains and scales.

Cleavage none. Fracture hackly. Malleable and ductile. H. = 4–4·5. G. = 14–19 native; 21–22 chem. pure. Luster metallic. Color and streak whitish steel-gray; shining. Sometimes magnetipolar.

Comp.—Platinum alloyed with iron, iridium, osmium, and other metals.

Most platinum yields from 8 to 15 or even 18 per cent of iron, 0·5 to 2 p. c. palladium, 1 to 3 p. c. rhodium and iridium, a trace of osmium and finally 0·5 to 2 p. c. or more of copper.

Var.—1. *Ordinary. Non-magnetic* or only slightly magnetic. G. = 16·5–18·0 mostly. 2. *Magnetic.* G. about 14. Much platinum is magnetic, and occasionally it has polarity. The magnetic property seems to be connected with high percentage of iron (iron-platinum, Eisenplatin *Germ.*), although this distinction does not hold without exception.

Pyr., etc.—B.B. infusible. Not affected by borax or salt of phosphorus, except in the state of fine dust, when reactions for iron and copper may be obtained. Soluble only in heated nitro-hydrochloric acid.

Diff.—Distinguished by its color, malleability, high specific gravity, infusibility and insolubility in ordinary acids.

Obs.—Platinum was first found in pebbles and small grains, associated with iridium, gold, chromite, etc., in the alluvial deposits of the river Pinto, in the district of Choco, Colombia, S. America, where it received its name *platina* (platina del Pinto) from *plata*, silver. In Russia (discovered in 1822) occurs in alluvial material in the Ural at Nizhni Tagilsk, and with chromite in a serpentine probably derived from a peridotite; also in the Goroblagodatsk district. Also found on Borneo; in New Zealand, from a region characterized by a chrysolite rock with serpentine; in New South Wales, in the Broken Hill district, and in gold washings at various points.

In California, in the Klamath region, at Cape Blanco, etc., not abundant: in the gold washings of Cherokee, Butte Co.; at St. François, Beauce Co., Quebec; at several points in British Columbia.

Iridium. Platin-iridium. Iridium with platinum and other allied metals. Occurs usually in angular grains of a silver-white color. H. = 6–7. G. = 22·6–22·8. With the platinum of the Urals and Brazil.

IRIDOSMINE. Osmiridium.

Rhombohedral. Usually in irregular flattened grains.

Cleavage: *c* perfect. Slightly malleable to nearly brittle. H. = 6–7. G. = 19·3–21·12. Luster metallic. Color tin-white to light steel-gray. Opaque.

Comp., Var.—Iridium and osmium in different proportions. Some rhodium, platinum, ruthenium, and other metals are usually present.

Var.—1. *Nevyanskite.* H. = 7; G. = 18·8–19·5. In flat scales; color tin-white. Over 40 p. c. of iridium. 2. *Siserskite.* In flat scales, often six-sided, color grayish white, steel-gray. G. = 20–21·2. Not over 30 p. c. of iridium. Less common than the light-colored variety.

Diff.—Distinguished from platinum by greater hardness and by its lighter color.

Obs.—Occurs with platinum in South America; in the Ural mountains; in auriferous drift in New South Wales. Rather abundant in the auriferous beach-sands of northern California.

Palladium.—Palladium, alloyed with a little platinum and iridium. Mostly in grains. H. = 4·5–5. G. = 11·3–11·8. Color whitish steel-gray. Occurs with platinum in Brazil; also from the Urals.

Allopalladium. Palladium under the rhombohedral system (?). From Tilkerode in the Harz, in small hexagonal tables with gold.

IRON.

Isometric. Usually massive, rarely in crystals.

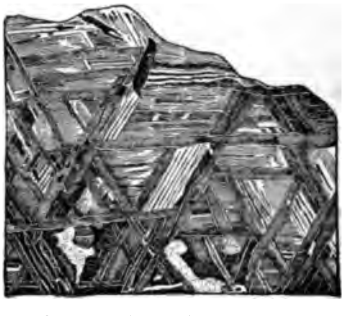
Cleavage: *a* perfect; also a lamellar structure ∥ *o* and ∥ *d*. Fracture hackly. Malleable. H. = 4–5. G. = 7·3–7·8. Luster metallic. Color steel-gray to iron-black. Strongly magnetic.

Var.—1. **Terrestrial Iron.** Found in masses, occasionally of great size, as well as in small embedded particles, in basalt at Blaafjeld, Ovifak (or Uifak), Disko Island, West Greenland; also elsewhere on the same coast. This iron contains 1 to 2 p. c. of Ni. Some other occurrences, usually classed as meteoric, may be in fact terrestrial; *e.g.*, the Santa Catharina iron of Brazil discovered in 1875.

A nickeliferous metallic iron ($FeNi_2$) called *awaruite* occurs in the drift of the Gorge river, which empties into Awarua Bay on the west coast of the south island of New Zealand; associated with gold, platinum, cassiterite, chromite; probably derived from a partially serpentinized peridotite. *Josephinite* is a nickel-iron (Fe_2Ni_5) from Oregon, occurring in stream gravel. Native iron also occurs sparingly in some basalts; reported from gold or platinum washings at various points.

2. **Meteoric Iron.** Native iron also occurs in most meteorites, forming in some cases (*a*) the entire mass (*iron meteorites*); also (*b*) as a spongy, cellular matrix in which are embedded grains of chrysolite or other silicates (*siderolites*); (*c*) in grains or scales disseminated more or less freely throughout a stony matrix (*meteoric stones*). Rarely a meteorite consists of a single crystalline individual (Braunau) with numerous twinning lamellæ ∥ *o*. Cubic cleavage sometimes observed; also an octahedral, less often dodecahedral lamellar structure. Etching with dilute nitric acid (or iodine) commonly develops a crystalline structure (called *Widmanstätten figures*) (Fig. 588); usually consisting of lines or bands crossing at various angles according to the direction of the section, at 60° if ∥ *o*, 90° | *a*, etc. They are formed by the edges of crystalline plates, usually | *o*, of the nickeliferous iron of different composition (*kamacite, tænite, plessite*), as shown by the fact that they are differently attacked by the acid. Irons with cubic structure and with twinning lamellæ (*e.g.*, Braunau) have a series of fine lines corresponding to those developed by etching (*Neumann lines*). A damascene luster is also produced in some cases, due to quadrilateral depressions. Some irons show no distinct crystalline structure upon etching.

588.



Glorieta Mt., New Mexico.

The exterior of masses of meteoric iron is usually more or less deeply pitted with rounded thumblike depressions, and the surface at the time of fall is covered with a film of iron oxide in fine ridges showing lines of flow due to the melting caused by the heat developed by the resistance of the air; this film disappears when the iron is exposed to the weather.

Meteoric iron is always alloyed with nickel, which is usually present in amounts varying from 5 to 10 p. c., sometimes much more; small amounts of other metals, as cobalt, manganese, tin, copper, chromium, are also often present. Occluded gases can usually be detected. Graphite, in seams or nodules, also troilite (iron sulphide), schreibersite (iron-nickel phosphide) are common in masses of meteoric iron; diamond, daubreelite, etc., are rare. *Cohenite*, sometimes identified, is $(Fe,Ni,Co)_3C$ in tin-white crystals.

II. SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, ANTIMONIDES.

The sulphides, etc, fall into two Groups according to the character of the positive element.

I. Sulphides, Selenides, Tellurides of the Semi-Metals.

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides of the Metals.

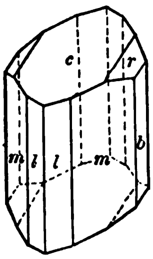
I. Sulphides, etc., of the Semi-Metals.

This section includes one distinct group, the Stibnite Group, to which orpiment is related; the other species included stand alone.

REALGAR.

Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c} = 1{\cdot}4403 : 1 : 0{\cdot}9729$; $\beta = 66^\circ\ 5'$.

589.



Nagyág.

mm''', 110 ∧ 1$\bar{1}$0 = 105° 34'. *rr'*, 012 ∧ 0$\bar{1}$2 = 47° 57'.

Crystals short prismatic; striated vertically. Also granular, coarse or fine; compact; as an incrustation.

Cleavage: *b*, rather perfect. Fracture small conchoidal. Sectile. H. = 1·5–2. G. = 3·556. Luster resinous. Color aurora-red or orange-yellow. Streak varying from orange-red to aurora-red. Transparent—translucent.

Comp.—Arsenic monosulphide, AsS = Sulphur 29·9, arsenic 70·1 = 100.

Pyr., etc.—In the closed tube melts, volatilizes, and gives a transparent red sublimate; in the open tube (if heated very slowly) sulphurous fumes, and a white crystalline sublimate of arsenic trioxide. B.B. on charcoal burns with a blue flame, emitting arsenical and sulphurous odors. Soluble in caustic alkalies.

Obs.—Often associated with orpiment; occurs with ores of silver and lead, at Felsöbánya and Kapnik, Hungary; Nagyág; Joachimsthal; Schneeberg; Andreasberg; Binnenthal, Switzerland, in dolomite; near Julamerk in Kurdistan. In the U. S., in Iron county, Utah; also in California, San Bernardino Co.; Trinity Co., in calcite. Norris Geyser Basin, Yellowstone Park, as a deposition from the hot waters. The name *realgar* is from the Arabic Rahj al ghār, *powder of the mine.*

ORPIMENT.

Monoclinic.* Axes $\grave{a} : \bar{b} : \dot{c} = 1{\cdot}2061 : 1 : 0{\cdot}6743$, $\beta = 90^\circ$. approx.

Crystals small, rarely distinct. Usually in foliated or columnar masses; sometimes with reniform surface.

Cleavage: *b* highly perfect, cleavage face vertically striated; *a* in traces; gliding-plane *c* (001). Sectile. Cleavage laminæ flexible, inelastic. H. = 1·5–2. G. = 3·4–3·5. Luster pearly on *b* (cleavage); elsewhere resinous. Color lemon-yellow of several shades; streak the same, but paler. Subtransparent—subtranslucent.

Comp.—Arsenic trisulphide, As_2S_3 = Sulphur 39·0, arsenic 61·0 = 100.

---

* See Groth, Tab. Ueb., 17, 1898. The fine crystals from Mercur, Utah, are distinctly monoclinic in habit (Penfield).

Pyr., etc.—In the closed tube, fuses, volatilizes, and gives a dark yellow sublimate; other reactions the same as under realgar. Dissolves in aqua regia and caustic alkalies.

Diff.—Distinguished by its fine yellow color, pearly luster, easy cleavage, and flexibility when in plates.

Obs.—Occurs in small crystals in clay at Tajowa, in Upper Hungary; in foliated and fibrous masses, at Moldawa in the Banat; at Kapnik and Felsöbánya in metalliferous veins; at the Solfatara near Naples. Near Julamerk in Kurdistan a large Turkish mine. Occurs with realgar in seams in compact clay beneath lava in Iron county, Utah; also finely crystallized at Mercur. Among the deposits of the Steamboat Springs, Nevada; also with realgar in the Yellowstone Park.

The name orpiment is a corruption of its Latin name auripigmentum, "*golden paint,*" given in allusion to the color, and also because the substance was supposed to contain gold.

Stibnite Group.

		$\breve{a} : \breve{b} : \dot{c}$
Stibnite	Sb_2S_3	0·9926 : 1 : 1·0179
Bismuthinite	Bi_2S_3	0·9679 : 1 : 0·9850
Guanajuatite	Bi_2Se_3	1 : 1 approx.

The species of the Stibnite Group crystallize in the orthorhombic system and have perfect brachydiagonal cleavage, yielding flexible laminæ.

The species orpiment is in physical properties somewhat related to stibnite, but seems to be monoclinic in crystallization. Groth notes that the oxide, As_2O_3, is monoclinic in claudetite, while the corresponding compound, Sb_2O_3 (valentinite), is orthorhombic; further he remarks on the relation in form and physical characters between orpiment and claudetite.

STIBNITE. Antimonite, Antimony Glance, Gray Antimony, Antimonglanz *Germ.*

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}9926 \cdot 1 : 1{\cdot}0179$.

mm‴, 110 ∧ $1\bar{1}0$ = 89° 34′.
pp′, 111 ∧ $\bar{1}11$ = 71° 24½′.
ss′, 113 ∧ $\bar{1}13$ = 35° 52½′.
ss‴, 113 ∧ $1\bar{1}3$ = 35° 36′.

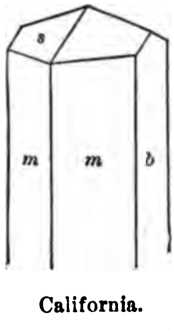
bv, 010 ∧ 121 = 35° 8′.
bη, 010 ∧ 353 = 40° 10½′.
bτ, 010 ∧ 343 = 46° 33′.
bp, 010 ∧ 111 = 54° 36′.

Crystals prismatic; striated or furrowed vertically; often curved or twisted (cf. p. 148). Common in confused aggregates or radiating groups of acicular crystals; massive, coarse or fine columnar, less often granular to impalpable.

Cleavage: *b* highly perfect. Slightly sectile. Fracture small subconchoidal. H. = 2. G. = 4·52–4·62. Luster metallic, highly splendent on cleavage or fresh crystalline surfaces. Color and streak lead-gray, inclining to steel-gray: subject to blackish tarnish, sometimes iridescent.

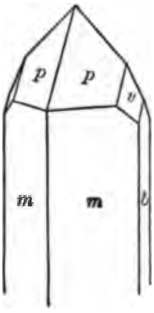
Comp.—Antimony trisulphide, Sb_2S_3 = Sulphur 28·6, antimony 71·4 = 100. Sometimes auriferous, also argentiferous.

590.



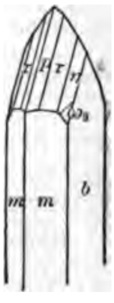
California.

591.



Hungary.

592.



Japan.

Pyr., etc.—Fuses very easily (at 1), coloring the flame greenish blue. In the open tube sulphurous (SO_2) and antimonial (chiefly Sb_2O_4) fumes, the latter condensing as a white sublimate which B.B. is non-volatile. On charcoal fuses, spreads out, gives sulphurous fumes, and coats the coal white with oxide of antimony; this coating treated in R. F. volatilizes and tinges the flame greenish blue. When pure perfectly soluble in hydrochloric acid: in nitric acid decomposed with separation of antimony pentoxide.

Diff.—Distinguished (*e.g.*, from galena) by cleavage, color, softness; also by its fusibility and other blowpipe characters. It is harder than graphite. Resembles sometimes certain of the rarer sulphantimonites of lead, but yields no lead coating on charcoal.

Obs.—Occurs with quartz in beds or veins in granite and gneiss, often accompanied with various other antimony minerals produced by its alteration. Also associated in metalliferous deposits with sphalerite, galena, cinnabar, barite, quartz; sometimes accompanies native gold.

Occurs at Wolfsberg, in the Harz; Braunsdorf, near Freiberg; Přibram; Casparizeche, near Arnsberg, Westphalia; Felsöbánya, Hungary; in Cornwall, abundant Also abundant in Borneo; in Victoria and New South Wales. Groups of large splendent crystals have come from the antimony mines in the Province of Iyo, island of Shikoku, Japan.

In the United States occurs as a vein of some extent in Sevier county, Ark.; in California at San Emigdio, Kern county, and near Alta, Benito Co.; in the Humboldt mining region in Nevada; in Iron county, Utah. In New Brunswick in Prince William, York county, 20 m. from Fredericton; in Rawdon township, Hants Co., N. S.

Metastibnite. An amorphous brick-red deposit of antimony trisulphide, Sb_2S_3, occurring with cinnabar and arsenic sulphide upon siliceous sinter at Steamboat Springs, Washoe Co., Nevada.

BISMUTHINITE. Bismuth Glance. Wismuthglanz *Germ.*

Orthorhombic. Rarely in acicular crystals. $mm''' = 88° 8'$. Usually massive, foliated or fibrous.

Cleavage: *b* perfect. Somewhat sectile. H. = 2. G. = 6·4–6·5. Luster metallic. Streak and color lead-gray, inclining to tin-white, with a yellowish or iridescent tarnish. Opaque.

Comp.—Bismuth trisulphide, Bi_2S_3 = Sulphur 18·8, bismuth 81·2 = 100. Sometimes contains a little copper and iron.

Pyr., etc.—Fusibility = 1. In the open tube sulphurous fumes, and a white sublimate which B.B. fuses into drops, brown while hot and opaque yellow on cooling. On charcoal at first gives sulphurous fumes; then fuses with spirting, and coats the coal with yellow bismuth oxide; with potassium iodide a bright red coating of bismuth iodide is obtained. Dissolves readily in hot nitric acid, and a white precipitate falls on diluting with water.

Obs.—Found at Brandy Gill, Carrock Fells, in Cumberland; near Redruth, etc. In France at Meymac, Corrèze; at Johanngeorgenstadt, Schneeberg; at Wittichen, Baden; at Riddarhyttan, Sweden; near Sorata, Bolivia.

In the U. S., occurs with gold in Rowan Co., N. C., at the Barnhardt vein; sparingly at Willimantic, Conn.; abundant in Beaver Co . Utah.

Guanajuatite. Frenzelite: Selenwismuthglanz *Germ.* Bismuth selenide, Bi_2Se_3, sometimes with a small amount of sulphur replacing selenium. In acicular crystals; also massive, granular, foliated or fibrous. Cleavage: *b* distinct. H. = 2·5–3·5. G. = 6·25–6·62. Luster metallic. Color bluish gray. From the Santa Catarina mine, near Guanajuato, Mexico.

TETRADYMITE. Tellurwismuth *Germ.*

Rhombohedral. Crystals small, indistinct. Commonly in bladed forms, foliated to granular massive.

Cleavage: basal, perfect. Laminæ flexible; not very sectile. H. = 1·5–2; soils paper. G. = 7·2–7·6. Luster metallic, splendent. Color pale steel-gray.

Comp., Var.—Consists of bismuth and tellurium, with sometimes sulphur and a trace of selenium; the analyses for the most part afford the general formula $Bi_2(Te,S)_3$.

Var.—1. *Free from sulphur.* Bi_2Te_3 = Tellurium 48·1, bismuth 51·9. G. = 7·642 from Dahlonega. Var. 2. *Sulphurous.* $2Bi_2Te_3.Bi_2S_3$ = Tellurium 36·4, sulphur 4·6, bismuth

59 0 = 100. This is the more common variety and includes the *tetradymite* of Haidinger in crystals from Schubkau.

Pyr.—In the open tube a white sublimate of tellurium dioxide, which B.B. fuses to colorless drops. On charcoal fuses, gives white fumes, and entirely volatilizes; tinges the R.F. bluish green; coats the coal at first white (TeO_2), and finally orange-yellow (Bi_2O_3); some varieties give sulphurous and selenous odors.

Obs.—Occurs at Schubkau near Schemnitz; Rezbanya; Orawitza in the Banat; Tellemark in Norway; Bastnaes mine, near Riddarhyttan, Sweden. In the U. S., in Virginia, at the Whitehall gold mines, Spottsylvania Co.; in Davidson Co., N. C., and in the gold washings of Burke and McDowell counties, etc.; similarly in Montana. At the Montgomery mine, Arizona. Named from τετράδυμος, *fourfold*, in allusion to complex twin crystals sometimes observed.

Joseite.—A bismuth telluride (Te 80 p. c., also S and Se). G. = 7 9. San José, Brazil.

Wehrlite. A foliated bismuth telluride (Te 30 p. c.) of doubtful formula. G. = 8·4. Deutsch-Pilsen, Hungary.

MOLYBDENITE. Molybdänglanz *Germ.*

Crystals hexagonal in form, tabular, or short prisms slightly tapering and horizontally striated. Commonly foliated, massive or in scales; also fine granular.

Cleavage: basal eminent. Laminæ very flexible, but not elastic. Sectile. H. = 1–1·5. G. = 4·7–4·8. Luster metallic. Color pure lead-gray; a bluish gray trace on paper. Opaque. Feel greasy.

Comp.—Molybdenum disulphide, MoS_2 = Sulphur 40·0, molybdenum 60·0 = 100.

Pyr., etc—In the open tube sulphurous fumes and a pale yellow crystalline sublimate of molybdenum trioxide (MoO_3). B.B. in the forceps infusible, imparts a yellowish-green color to the flame; on charcoal the pulverized mineral gives in O.F. a strong odor of sulphur, and coats the coal with crystals of molybdic oxide, yellow while hot, white on cooling; near the assay the coating is copper-red, and if the white coating be touched with an intermittent R.F., it assumes a beautiful azure-blue color. Decomposed by nitric acid, leaving a white or grayish residue.

Diff.—Much resembles graphite in softness and structure (see p. 273), but has a bluer

yields sulphur on charcoal.

minated through, granite, gneiss, zircon-
At Numedal, Sweden; Arendal
, Bohemia; near Miask, Urals;
in Cumberland; at several of the

gneiss; in *Vermont*, at Newport;
southeast of Warwick; in *Penn.*,
N. C. In *Canada*, at St. Jérôme,
so in Aldfield township, Pontiac

some substances containing lead,
e compounds of antimony. The
shed by Scheele in 1778–79.

distinction between g

Roast molybdenite in the tube
to drive off the sulphur; heat
the powder in a porcelain
dish & add a few drops of
conc. H_2SO_4; blue coloration

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides of the Metals.

The sulphides of this second section fall into four divisions depending upon the proportion of the negative element present. These divisions with the groups belonging to them are as follows:

59 0 = 100. This is the more common variety and includes the *tetradymite* of Haidinger in crystals from Schubkau.

Pyr.—In the open tube a white sublimate of tellurium dioxide, which B.B. fuses to colorless drops. On charcoal fuses, gives white fumes, and entirely volatilizes; tinges the R.F. bluish green; coats the coal at first white (TeO_2), and finally orange-yellow (Bi_2O_3); some varieties give sulphurous and selenous odors.

Obs.—Occurs at Schubkau near Schemnitz; Rezbanya; Orawitza in the Banat; Tellemark in Norway; Bastnaes mine, near Riddarhyttan, Sweden. In the U. S., in Virginia, at the Whitehall gold mines, Spottsylvania Co.; in Davidson Co., N. C., and in the gold washings of Burke and McDowell counties, etc.; similarly in Montana. At the Montgomery mine, Arizona. Named from τετράδυμος, *fourfold*, in allusion to complex twin crystals sometimes observed.

Joseite.—A bismuth telluride (Te 80 p. c., also S and Se). G. = 7·9. San José, Brazil.

Wehrlite. A foliated bismuth telluride (Te 30 p. c.) of doubtful formula. G. = 8·4. Deutsch-Pilsen, Hungary.

MOLYBDENITE. Molybdänglanz *Germ.*

Crystals hexagonal in form, tabular, or short prisms slightly tapering and horizontally striated. Commonly foliated, massive or in scales; also fine granular.

Cleavage: basal eminent. Laminæ very flexible, but not elastic. Sectile. H. = 1–1·5. G. = 4·7–4·8. Luster metallic. Color pure lead-gray; a bluish gray trace on paper. Opaque. Feel greasy.

Comp.—Molybdenum disulphide, MoS_2 = Sulphur 40·0, molybdenum 60·0 = 100.

Pyr., etc—In the open tube sulphurous fumes and a pale yellow crystalline sublimate of molybdenum trioxide (MoO_3). B.B. in the forceps infusible, imparts a yellowish-green color to the flame; on charcoal the pulverized mineral gives in O.F. a strong odor of sulphur, and coats the coal with crystals of molybdic oxide, yellow while hot, white on cooling; near the assay the coating is copper-red, and if the white coating be touched with an intermittent R.F., it assumes a beautiful azure-blue color. Decomposed by nitric acid, leaving a white or grayish residue.

Diff.—Much resembles graphite in softness and structure (see p. 278), but has a bluer trace on paper and readily yields sulphur on charcoal.

Obs.—Generally occurs embedded in, or disseminated through, granite, gneiss, zircon-syenite, granular limestone, and other crystalline rocks. At Numedal, Sweden; Arendal and Laurvik in Norway; Altenberg, Saxony; Zinnwald, Bohemia; near Miask, Urals; Chessy in France; in Italy, at Traversella; Carrock Fells, in Cumberland; at several of the Cornish mines.

In *Maine*, at Blue Hill Bay; in *Conn.*, at Haddam, in gneiss; in *Vermont*, at Newport; in *N Hampshire*, at Westmoreland; in *N. York*, two miles southeast of Warwick; in *Penn.*, in Chester, near Reading; near Concord, Cabarrus Co., N. C. In *Canada*, at St. Jérôme, Quebec; in large crystals in Renfrew county, Ontario; also in Aldfield township, Pontiac Co., Quebec.

Named from μόλυβδος, *lead;* the name, first given to some substances containing lead, later included graphite and molybdenite, and even some compounds of antimony. The distinction between graphite and molybdenite was established by Scheele in 1778–79.

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides of the Metals.

The sulphides of this second section fall into four divisions depending upon the proportion of the negative element present. These divisions with the groups belonging to them are as follows:

A. Basic Division.

B. Monosulphides, Monotellurides, etc., $\overset{I}{R}_2S$, $\overset{II}{R}S$, etc.

1. **Galena Group.** Isometric, normal group.
2. **Chalcocite Group.** Orthorhombic.
3. **Sphalerite Group.** Isometric-tetrahedral.
4. **Cinnabar—Wurtzite—Millerite Group.** Hexagonal and rhombohedral.

C. Intermediate Division.

Embraces Melonite, Te_2S_3; also Bornite, $3Cu_2S.Fe_2S_3$; Linnæite, $CoS.Co_2S_3$; Chalcopyrite, $Cu_2S.Fe_2S_3$; etc.

D. Disulphides, Diarsenides, etc., RS_2, RAs_2, etc.

1. **Pyrite Group.** Isometric-pyritohedral.
2. **Marcasite Group.** Orthorhombic.

A. Basic Division.

The basic division embraces several rare basic compounds of silver or copper chiefly with antimony and arsenic. Of these the crystallization of dyscrasite only is known.

DYSCRASITE. Antimonsilber *Germ.*

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·5775 : 1 : 0·6718$. Crystals rare, pseudohexagonal in angles ($mm''' = 60° 1'$) and by twinning. Also massive. Fracture uneven. Sectile. H. = 3·5–4. G. = 9·44–9·85. Luster metallic. Color and streak silver-white, inclining to tin-white; sometimes tarnished yellow or blackish. Opaque.

Comp.—A silver antimonide, including Ag_3Sb = Antimony 27·1, silver 72·9 = 100, and Ag_6Sb = Antimony 15·7, silver 84·3 = 100, and perhaps other compounds.

Analyses vary widely, some conforming also to Ag_2S. $Ag_4(Sb,As)_3$, etc. By some authors classed with chalcocite.

Pyr., etc.—B.B. on charcoal fuses to a globule, coating the coal with white antimony trioxide and finally giving a globule of almost pure silver. Soluble in nitric acid, leaving antimony trioxide.

Obs.—Occurs near Wolfach, Baden; Wittichen; Andreasberg in the Harz; Allemont, France. Named from *δυσκρᾶσις, a bad alloy.*

Horsfordite. A silver-white, massive copper antimonide, probably Cu_6Sb (Sb 24 p. c.). G. = 8·8. Asia Minor, near Mytilene.

HUNTILITE, ANIMIKITE. The ores from Silver Islet, Lake Superior, apparently contain a silver arsenide (*huntilite*, Ag_3As?) and perhaps also a silver antimonide (*animikite*, Ag_9Sb?), the latter related to or identical with dyscrasite.

Domeykite.—Copper arsenide, Cu_3As. Reniform and botryoidal; also massive, disseminated. G. = 7·2–7·75. Luster metallic. Color tin-white to steel-gray, readily tarnished. From several Chilian mines; also Zwickau, Saxony. In N. America, with niccolite at Michipicoten Island, L. Superior.

Algodonite. Copper arsenide, Cu_6As (As 16·5 p. c.); G. = 7·62. Resembles domeykite. From Chili; also L. Superior.

Whitneyite. Copper arsenide, Cu_9As (As 11·6 p. c.). G. = 8·4–8·6. Color pale reddish white. From Houghton Co., Michigan; Sonora, L. California.

Chilenite. Perhaps Ag_6Bi. Copiapo, Chili.

Stützite. A rare silver telluride (Ag_4Te?). Probably from Nagyág.

B. Monosulphides, Monotellurides, etc., $\overset{I}{R}_2S$, $\overset{II}{R}S$, etc.

1. Galena Group. Isometric.

Galena	PbS	**Argentite**	Ag_2S
Also,	$(Pb,Cu_2)S$, $(Cu_2,Pb)S$	Jalpaite	$(Ag,Cu)_2S$
Altaite	$PbTe$	**Hessite**	Ag_2Te
Clausthalite	$PbSe$	**Aguilarite**	Ag_2Se
Naumannite	$(Ag_2,Pb)Se$		

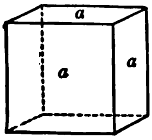
The following, known only in massive form, probably also belong here:

Berzelianite	Cu_2Se	**Zorgite**	$(Pb,Cu_2,Ag_2)Se$?
Lehrbachite	$(Pb,Hg_2)Se$	**Crookesite**	$(Cu,Tl,Ag)_2Se$
Eucairite	$Cu_2Se.Ag_2Se$		

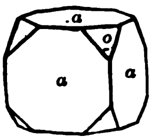
The GALENA GROUP embraces a number of monosulphides, etc., of the related metals, silver, copper, lead, and mercury. These crystallize in the normal group of the isometric system, and several show perfect cubic cleavage. These characters are most distinctly exhibited in the type species, galena.

GALENA, or GALENITE. Lead glance. Bleiglanz *Germ.*

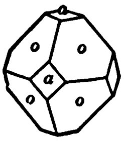
593.



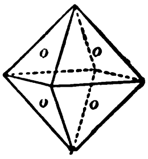
594.



595.



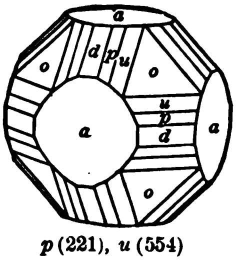
596.



Isometric. Commonly in cubes, or cubo-octahedrons, less often octahedral. Also in skeleton crystals, reticulated, tabular. Twins: tw. pl. *o*, both contact- and penetration-twins (Figs. 363, 366, p. 123), sometimes repeated; twin crystals often tabular ∥ *o*. Also other tw. planes giving polysynthetic tw. lamellæ. Massive cleavable, coarse or fine granular, to impalpable; occasionally fibrous or plumose.

Cleavage: cubic, highly perfect; less often octahedral. Fracture flat subconchoidal or even. H. = 2·5–2·75. G. = 7·4–7·6. Luster metallic. Color and streak pure lead-gray. Opaque.

597.



p (221), u (554)

Comp., Var.—Lead sulphide, PbS = Sulphur 13·4, lead 86·6 = 100. Often contains silver, and occasionally selenium, zinc, cadmium, antimony, bismuth, copper, as sulphides; besides, also, sometimes native silver and gold.

Var.—1. *Ordinary.* (*a*) Crystallized; (*b*) somewhat fibrous and plumose; (*c*) cleavable, granular coarse or fine; (*d*) cryptocrystalline. The variety with octahedral cleavage is rare; the usual cubic cleavage is obtained readily after heating to 200° or 300°; the peculiar cleavage may be connected with the bismuth usually present.

2. *Argentiferous.* All galena is more or less argentiferous, and no external characters serve to distinguish the kinds that are much so from those that are not. The silver is detected by cupellation, and may amount from a few thousandths of one per cent to one per cent or more; when mined for silver it ranks as a *silver ore.*

3. Containing arsenic, or antimony, or a compound of these metals, as impurity. Here belong *bleischweif* from Clausthal with 0·22 Sb, and *steinmannite* from Přibram, with both arsenic and antimony.

Pyr.—In the open tube gives sulphurous fumes. B.B. on charcoal fuses, emits sulphurous fumes, coats the coal yellow near the assay (PbO) and white with a bluish border at a distance ($PbSO_4$, chiefly), and yields a globule of metallic lead. Decomposed by strong nitric acid with the separation of some sulphur and the formation of lead sulphate.

Diff.—Distinguished, except in very fine granular varieties, by its cubic cleavage; the color and the high specific gravity are characteristic; also the blowpipe reactions.

Obs.—One of the most widely distributed of the metallic sulphides. Occurs in beds and veins, both in crystalline and uncrystalline rocks. It is often associated with pyrite, marcasite, sphalerite, chalcopyrite, arsenopyrite, etc., in a gangue of quartz, calcite, barite or fluorite, etc.; also with cerussite, anglesite, and other salts of lead, which are frequent results of its alteration. It is also common with gold, and in veins of silver ores.

At Freiberg in Saxony it occupies veins in gneiss; in Spain, in granite at Linares, also in Catalonia, Grenada, and elsewhere; at Clausthal and Neudorf in the Harz, and at Přibram in Bohemia, it forms veins in clay slate; similarly in Styria; at Sala in Sweden in veins in granular limestone; through the graywacke of Leadhills and the killas of Cornwall, in veins; filling cavities in the Subcarboniferous limestone in Derbyshire, Cumberland, and the northern districts of England; also at Bleiberg, Carinthia. In the English mines it is associated with calcite, pearl spar, fluorite, barite, witherite, calamine, and sphalerite. Other localities are Joachimsthal, Bohemia; Poullaouen and Huelgoet, Brittany; Sardinia; Nerchinsk, East Siberia; Australia; Chili; Bolivia, etc.

Extensive deposits of this ore in the United States exist in Missouri, Illinois, Iowa, and Wisconsin. The ore occurs not in veins but filling cavities or chambers in stratified limestone, of different periods of the Lower Silurian, especially the Trenton, also in part Subcarboniferous. It is associated with sphalerite, smithsonite, calcite, pyrite. The Missouri mines are situated in the counties of Washington, Jefferson, Madison and others. Good crystals are obtained at Joplin, Jasper Co. Also occurs in *New York*, at Rossie, St. Lawrence Co., in crystals with calcite and chalcopyrite; in *Maine*, at Lubec, etc.; in *Mass.*, at Southampton, Newburyport, etc; in *Penn.*, at Phenixville and elsewhere; in *Virginia*, at Austin's mines in Wythe Co., and other places; in *Tenn.*, at Haysboro, near Nashville; in *Mich.*, in the Lake Superior copper district and on the N. shore of L. Superior; in *California*, at many of the gold mines; in *Nevada*, abundant in the Eureka district; in *Arizona*, in the Castle Dome, Eureka, and other districts. In *Colorado*, at Leadville there are productive mines of argentiferous galena, also at Georgetown, the San Juan district and elsewhere. Mined for silver in the Cœur d'Alêne region in Idaho; also at various points in Montana.

The name galena is from the Latin *galena* (*γαλήνη*), a name given to lead ore or the dross from melted lead.

CUPROPLUMBITE. A massive mineral, from Chili, varying in characters from galena to those of chalcocite and covellite; composition, $Cu_2S.2PbS$(?). *Alisonite* is massive, deep indigo-blue quickly tarnishing; corresponds to $3Cu_2S.PbS$. From Mina Grande, Chili. Whether these and similar minerals represent definite homogeneous compounds, or only ill-defined alteration-products, is uncertain, and if so it is not clear whether they should be classed with isometric galena or with orthorhombic chalcocite.

Altaite. Lead telluride, AgTe Rarely in cubic crystals, usually massive with cubic cleavage. G. = 8·16. Color tin-white, with yellowish tinge tarnishing to bronze-yellow. From the Altai, with hessite; Coquimbo, Chili; California; Colorado.

Clausthalite. Lead selenide, PbSe. Commonly in fine granular masses resembling galena. Cleavage: cubic. G. = 7·6–8·8. Color lead-gray, somewhat bluish. From the Harz, at Clausthal, etc.; Cacheuta mine, Mendoza, S. A. *Tilkerodite* is a cobaltiferous variety.

Naumannite. Silver-lead telluride (Ag_2,Pb)Se. In cubic crystals; also massive, granular, in thin plates. Cleavage: cubic. G. = 8·0. Color and streak iron-black. From Tilkerode in the Harz.

ARGENTITE. Silver Glance. Silberglanz *Germ.*

Isometric. Crystals often octahedral, also *a*, *o*; often distorted, frequently grouped in reticulated or arborescent forms; also filiform. Massive; embedded; as a coating.

Cleavage: *a*, *d* in traces. Fracture small subconchoidal. Perfectly sectile.

H. = 2–2·5. G. = 7·20–7·36. Luster metallic. Color and streak blackish lead-gray; streak shining. Opaque.

Comp.—Silver sulphide, Ag_2S = Sulphur 12·9, silver 87·1 = 100.

Pyr., etc.—In the open tube gives off sulphurous fumes. B.B. on charcoal fuses with intumescence in O. F., emitting sulphurous fumes, and yielding a globule of silver.

Diff.—Distinguished from other sulphides by being readily cut with a knife; also by yielding metallic silver on charcoal.

Obs.—Found at Freiberg. Joachimsthal, etc.; Schemnitz, Hungary; in Norway near Kongsberg; in the Altai; in Cornwall; Peru; Chili; Mexico at Guanajuato, etc.

Occurs in Nevada, at the Comstock lode; at the Silver King mine, Arizona; at mines near Port Arthur on north shore of Lake Superior; with native silver and copper in northern Michigan.

JALPAITE is a cupriferous argentite from Jalpa, Mexico.

Hessite. Silver telluride, Ag_2Te. Isometric. Usually massive, compact or fine-grained. Cleavage indistinct. Somewhat sectile. H. = 2·5–3. G. = 8·31–8·45. Color between lead-gray and steel-gray. From the Altai; at Nagyág in Transylvania; Rezbanya, Hungary; Chili, near Arqueros, Coquimbo. In the U. S., Calaveras Co., Cal.; Boulder Co., Colorado; Utah. This species also often contains gold and thus graduates toward petzite.

Petzite. $(Ag,Au)_2Te$ with Ag : Au = 3 : 1. Massive; granular to compact. Slightly sectil to brittle. H. = 2·5–3. G. = 8·7–9·02. Color steel-gray to iron-black; tarnishing. From Nagyág, Transylvania; Colorado; California.

Aguilarite. Silver selenide, Ag_2S and $Ag_2(S.Se)$. In skeleton dodecahedral crystals. Sectile. G. = 7·586. Color iron-black. From Guanajuato, Mexico.

Berzelianite. Copper selenide, Cu_2Se. In thin dendritic crusts and disseminated. G. = 6·71. Color silver-white tarnishing. From Skrikerum, Sweden; Lehrbach, in the Harz.

Lehrbachite. Selenide of lead and mercury, PbSe with HgSe. Massive, granular. G. = 7·8. Color lead-gray to iron-black. From Lehrbach, in the Harz.

Eucairite. $Cu_2Se.Ag_2Se$. Massive, granular. G. = 7·50. Color between silver-white and lead-gray. From the Skrikerum copper mine, Sweden; also Chili.

Zorgite. Selenide of lead and copper in varying amounts. Massive, granular. G. = 7–7·5. Color dark or light lead-gray. From the Harz; Cacheuta, Argentina.

Crookesite. Selenide of copper and thallium, also silver (1–5 p. c.), $(Cu,Tl,Ag)_2Se$. Massive. compact. G. = 6·9. Luster metallic. Color lead-gray. From the mine of Skrikerum, Sweden.

Umangite. $CuSe\,Cu_2Se$. Massive, fine-granular to compact. H. = 3. G. = 5·620. Color dark cherry-red. From La Rioja, Argentina.

2. Chalcocite Group.

		$\breve{a} : \bar{b} : \grave{c}$
Chalcocite	Cu_2S	0·5822 : 1 : 0·9701
Stromeyerite	$Ag_2S.Cu_2S$	0·5822 : 1 : 0·9668
Sternbergite	$Ag_2S.Fe_4S_5$	0·5832 : 1 : 0·8391
Frieseite		0·5970 : 1 : 0·7352
Acanthite	Ag_2S	0·6886 : 1 : 0·9944

The species of the CHALCOCITE GROUP crystallize in the orthorhombic system with a prismatic angle approximating to 60°; they are hence pseudo-hexagonal in form especially when twinned. The group is parallel to the Galena Group, since Cu_2 appears in isometric form in cuproplumbite and Ag_2S also in argentite. Some authors include dyscrasite here (see p. 286).

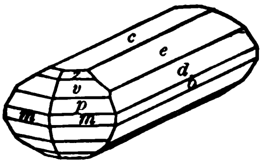
CHALCOCITE. Copper Glance. Redruthite. Kupferglanz *Germ.*

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·5822 : 1 : 0·9701$.

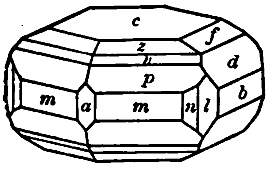
mm''', 110 ∧ $1\bar{1}0$ = 60° 25'. *cp*, 001 ∧ 111 = 62° 35½'.
dd', 021 ∧ $0\bar{2}1$ = 125° 28'. *pp'''*, 111 ∧ $1\bar{1}1$ = 58° 3½'.

Crystals pseudo-hexagonal in angle, also by twinning. (tw. pl. *m*). Often massive, structure granular to compact and impalpable.

598.



599.



Cleavage: *m* indistinct. Fracture conchoidal. Rather brittle. H. = 2·5–3. G. = 5·5–5·8. Luster metallic. Color and streak blackish lead-gray, often tarnished blue or green, dull. Opaque.

Comp.—Cuprous sulphide, Cu_2S = Sulphur 20·2, copper 79·8 = 100. Sometimes iron in small amount is present, also silver.

Pyr, etc.—In the open tube gives sulphurous fumes. B.B. on charcoal melts to a globule, which boils with spirting; the fine powder roasted at a low temperature on charcoal, then heated in R.F., yields a globule of metallic copper. Soluble in nitric acid.

Diff.—Resembles argenite but much more brittle; bornite has a different color on the fresh fracture and becomes magnetic B.B.

Obs.—Cornwall affords splendid crystals, especially the districts of Saint Just, Camborne, and Redruth (*redruthite*). Occurs at Joachimsthal, Bohemia; Tellemarken, Norway; compact and massive varieties in Siberia; Saxony; Mt. Catini mines in Tuscany; Mexico; S. America.

In the U. S., Bristol, Conn., has afforded large and brilliant crystals; also found at Simsbury and Cheshire; at Schuyler's mines, N. J.; in Nevada, in Washoe, Humboldt, Churchill and Nye counties; in Montana, massive at Butte City. Found in Canada, with chalcopyrite and bornite at the Acton mines and elsewhere in the province of Quebec.

Stromeyerite. $(Ag,Cu)_2S$, or $Ag_2S.Cu_2S$. Rarely in orthorhombic crystals, often twinned. Commonly massive, compact. H. = 2·5–3. G. = 6·15–6·3. Luster metallic. Color and streak dark steel-gray. From the Zmeinogorsk mine, Siberia; Silesia; also Chili; Zacatecas, Mexico; the Heintzelman mine in Arizona; Colorado.

STERNBERGITE.

Orthorhombic. Crystals tabular ‖ *c*. Commonly in fan-like aggregations; twins, tw. pl. *m*. Cleavage: *c*, highly perfect. Thin laminæ flexible, like tin-foil. H. = 1–1·5. G. = 4·215. Luster metallic. Color pinchbeck-brown. Streak black. Opaque.

Comp. $AgFe_2S_3$ or $Ag_2S.Fe_4S_5$ = Sulphur 30·4, silver 34·2, iron 35·4 = 100.

Obs.—Occurs with pyrargyrite and stephanite at Joachimsthal, Bohemia, and Johanngeorgenstadt, Saxony.

FRIESEITE. Near sternbergite. In thick tabular crystals; H. = 2·5; G. = 4·22. Color dark gray. Composition $Ag_2Fe_5S_8$. Occurs with marcasite at Joachimsthal.

Acanthite. Silver sulphide, Ag_2S, like argentite. In slender prismatic crystals (orthorhombic). Sectile. G. = 7·2–7·3. Color iron-black. Occurs at Joachimsthal; also at Freiberg, Saxony, and at Schneeberg.

It has been suggested that acanthite may be only argentite in distorted isometric crystals.

Sphalerite Group. RS. Isometric-tetrahedral.

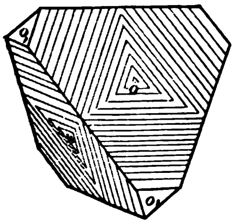
Sphalerite	ZnS	**Onofrite**	Hg(S,Se)	
Metacinnabarite	HgS	**Alabandite**	MnS	
Guadalcazarite	(Hg,Zn)S	**Coloradoite**	HgTe	Massive
Tiemannite	HgSe			

The Sphalerite Group embraces a number of sulphides, selenides, etc., of zinc, mercury, and manganese. These are isometric-tetrahedral in crystallization.

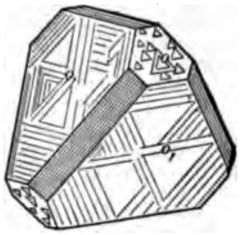
SPHALERITE, Zinc Blende or Blende. Black-Jack, Mock-Lead, False Galena *Engl.* Zinkblende *Germ.*

Isometric-tetrahedral. Often in tetrahedrons. Twins common: tw. pl. *o*; twinning often repeated, sometimes as polysynthetic lamellæ. Commonly massive cleavable, coarse to fine granular and compact; also foliated, sometimes fibrous and radiated or plumose; also botryoidal and other imitative shapes. Cryptocrystalline to amorphous, the latter sometimes as a powder.

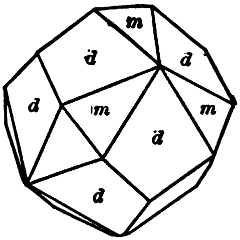
600.



601.



602.



m = (311)

Cleavage: dodecahedral, highly perfect. Fracture conchoidal. Brittle. H. = 3·5–4. G. = 3·9–4·1; 4·063 white, N. J. Luster resinous to adamantine. Color commonly yellow, brown, black; also red, green to white, and when pure nearly colorless. Streak brownish to light yellow and white. Transparent to translucent. Refractive index high: $n_y = 2·3692$ Na.

Comp.—Zinc sulphide, ZnS = Sulphur 33, zinc 67 = 100. Often containing iron and manganese, and sometimes cadmium, mercury and rarely lead and tin. Also sometimes contains traces of indium, gallium and thallium; may be argentiferous and auriferous.

Var.—1. *Ordinary*. Containing little or no iron; from colorless white to yellowish brown, sometimes green; G. = 4·0–4·1. The red or reddish-brown transparent crystallized kinds are sometimes called *ruby blende* or *ruby zinc*. The massive cleavable forms are the most common, varying from coarse to fine granular; also cryptocrystalline. *Schalenblende* (Germ.) is a closely compact variety, of a pale liver-brown color, in concentric layers with reniform surface; galena and marcasite are often interstratified. The fibrous forms (*faserige Zinkblende* Germ.) are chiefly wurtzite. A soft white amorphous form of zinc sulphide occurs in Cherokee Co., Kansas.

2. *Ferriferous; Marmatite.* Containing 10 p. c. or more of iron; dark-brown to black; G. = 3·9–4·05. The proportion of FeS to ZnS varies from 1 : 5 to 1 : 2, and the last ratio is that of the *christophite* of Breithaupt, a brilliant black sphalerite from St. Christophe mine, at Breitenbrunn, having G. = 3·91–3·923.

3. *Cadmiferous; Přibramite, Przibramite.* The amount of cadmium present in any sphalerite thus far analyzed is less than 5 per cent.

Pyr, etc.—Difficultly fusible. In the open tube sulphurous fumes, and generally changes color. B.B. on charcoal, in R.F., some varieties give at first a reddish-brown coating of cadmium oxide, and later a coating of zinc oxide, which is yellow while hot and white after cooling. With cobalt solution the zinc coating gives a green color when heated in O.F. Most varieties, after roasting, give with borax a reaction for iron. With soda on charcoal in R.F. a strong green zinc flame. Dissolves in hydrochloric acid with evolution of hydrogen sulphide.

Diff.—Varies widely in color and appearance, but distinguished by the resinous luster in all but deep black varieties; usually exhibits distinct cleavage; much softer than garnet; nearly infusible B.B.; yields a zinc coating on charcoal.

Obs.—Occurs very commonly in both crystalline and sedimentary rocks, and as a frequent associate of galena; also associated with chalcopyrite, barite, fluorite, siderite; common in silver mines. It often forms beds of considerable magnitude filling cavities in limestone.

Some of the chief localities for crystallized sphalerite are: Alston Moor in Cumberland, black variety; Derbyshire, St. Agnes and elsewhere in Cornwall; Oberlahnstein in Nassau, Ems, red; Andreasberg, yellow and brown; Neudorf in the Harz, Freiberg, Breitenbrunn, and other localities in Saxony, black and brown; Přibram, green or yellow, and Schlackenwald in Bohemia, black; Kapnik, Hungary, green or yellow; Nagyág, Transylvania, brown; Rodna, black; the Binnenthal in Switzerland, isolated crystals of great beauty, yellow to brown, in cavities of dolomite; Sala in Sweden; Nordmark, black, brown, also snow-white. A beautiful transparent variety yielding large cleavage masses is brought from Picos de Europa, Santander, Spain, where it occurs in a brown limestone. Fibrous varieties (see wurtzite) are obtained at Přibram; Geroldseck in Baden; Raibel; also in Cornwall. The original *marmatite* is from Marmato near Popayan, Italy.

Abounds with the lead ore of Missouri, Wisconsin, Iowa, and Illinois. In *N. York*, Sullivan Co., near Wurtzboro'; in St. Lawrence Co., at Mineral Point with galena; at the Ancram lead mine in Columbia Co.; in limestone at Lockport. In *Mass.*, at the Southampton lead mines. In *N. Hamp.*, at the Eaton lead mine; at Warren. In *Maine*, at the Lubec lead mines, etc. In *Conn.*, at Roxbury. In *N. Jersey*, a *white* variety (*cleiophane*) at Franklin Furnace. In *Penn.*, at the Wheatley and Perkiomen lead mines, in crystals; near Friedensville, Lehigh Co., a white waxy var. In *Virginia*, abundant at Austin's lead mines, Wythe Co. In *Michigan*, at Prince vein, Lake Superior, abundant. In *Illinois*, near Rosiclare, with galena and calcite; at Marsden's diggings, near Galena, in stalactites, with cryst. marcasite, and galena. In *Wisconsin*, at Mineral Point, in fine crystals. In *Tennessee*, at Haysboro', near Nashville. In *Missouri*, in beautiful crystallizations with galena, marcasite and calcite at Joplin and other points in the southwestern part of the state; the deposits here occur in limestone and are of great extent and value; also in adjoining parts of Kansas.

Named *blende* because, while often resembling galena, it yielded no lead, the word in German meaning *blind* or *deceiving*. *Sphalerite* is from σφαλερός, *treacherous*.

Metacinnabarite. Mercuric sulphide, HgS. In composition like cinnabar, but occurs in *black* tetrahedral crystals; also massive. G. = 7·8. From the Reddington mine, Lake county, California, with cinnabar, quartz and marcasite; also elsewhere sparingly.

Guadalcazarite. Near metacinnabarite, but contains zinc (up to 4 p. c.). Guadalcazar, Mexico.

Tiemannite. Selenquecksilber. Mercuric selenide, $HgSe$. Isometric-tetrahedral. Commonly massive; compact. G. = 8·19 Utah; 8·30–8·47 Clausthal. Luster metallic. Color steel-gray to blackish lead-gray. Streak nearly black. Occurs in the Harz; California, in the vicinity of Clear lake; Marysvale, Piute Co., Utah.

Onofrite. $Hg(S,Se)$ with Se = 4·5 to 6·5 p. c. San Onofre, Mexico; Marysvale, Utah.

Coloradoite. Mercuric telluride, $HgTe$. Massive. G. = 8·6. Color iron-black. Colorado.

Alabandite. Manganblende. Manganglanz *Germ.* Manganese sulphide, MnS. Isometric-tetrahedral; usually granular massive. Cleavage: cubic, perfect. G. = 3·95–4·04. Luster submetallic. Color iron-black. Streak green. Occurs at Nagyág, Transylvania; Kapnik, Hungary; Mexico; Peru; crystallized and massive on Snake River, Summit county, Colorado; Tombstone, Arizona.

Oldhamite. Calcium sulphide, CaS. In pale brown spherules with cubic cleavage in the Busti meteorite.

PENTLANDITE. Eisennickelkies *Germ.*

Isometric. Massive, granular. Cleavage: octahedral. Fracture uneven. Brittle. H. = 3·5–4. G. = 4·60. Luster metallic. Color light bronze-yellow. Streak light bronze-brown. Opaque. Not magnetic.

Comp.—A sulphide of iron and nickel, (Fe,Ni)S. In part, 2FeS.NiS = Sulphur 36·0, iron 42·0, nickel 22·0 = 100.

Obs.—Occurs with chalcopyrite near Lillehammer, Norway. The mineral from Sudbury, Ontario, is mined extensively for nickel; it shows distinct octahedral cleavage (or parting). The same locality also affords nickeliferous pyrite and pyrrhotite.

Troilite. Ferrous sulphide, FeS, occurring in nodular masses and in thin veins in many iron meteorites. G. = 4·75–4·82. Color tombac-brown. By some authors regarded as identical with pyrrhotite (p. 296).

4. Cinnabar-Wurtzite-Millerite Group. Rhombohedral or Hexagonal.

			$\dot{c}$		$\dot{c}$
Cinnabar	HgS	Rhombohedral-Trapezohedral	1·1453		
Covellite	CuS		1·1466		
Greenockite	CdS	Hexagonal-Hemimorphic	0·8109	or	0·9364
Wurtzite	ZnS	"	0·8175		0·9440
Millerite	NiS	Rhombohedral			0·9883
Niccolite	NiAs	"	0·8194		0·9462
Breithauptite	NiSb	"	0·8586		0·9915
Arite	Ni(Sb,As)				
Pyrrhotite	$Fe_{11}S_{12}$, etc.	Hexagonal	0·8701		1·0047

This fourth group among the monosulphides includes several subdivisions, as shown in the scheme above, and the relations of the species are not in all cases perfectly clear. It is to be noted that the sulphides of mercury and zinc, already represented in the sphalerite group, appear here again.

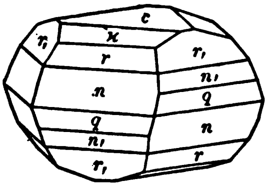
If, as suggested by Groth, the prominent pyramids of wurtzite, greenockite, etc., be made pyramids of the second series (*e.g.*, x = 11$\bar{2}$2, instead of 10$\bar{1}$1), then the values of $\dot{c}$ in the second column are obtained, which correspond to millerite. The form of several of these species, however, is only imperfectly known. A rhombohedral form for greenockite has been suggested.

CINNABAR. Zinnober, Schwefelquecksilber *Germ.*

Rhombohedral-trapezohedral. Axis $\dot{c}$ = 1·1453.

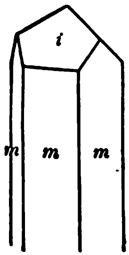
rr', 1011 ∧ $\bar{1}$011 = 87° 23′.
ii'', 4045 ∧ $\bar{4}$045 = 78° 0½′.
cr, 0001 ∧ 10$\bar{1}$1 = 52° 54′.

603.



κ (10$\bar{1}$4), n (20$\bar{2}$1), q (04$\bar{4}$1)

604.



Crystals usually rhombohedral or thick tabular in habit, rarely showing trapezohedral faces; also acicular prismatic. In crystalline incrustations, granular, massive; sometimes as an earthy coating.

Cleavage: *m* perfect. Fracture subconchoidal, uneven. Somewhat sectile. H. = 2–2·5. G. = 8·0–8·2. Luster adamantine, inclining to metallic when dark-colored, and to dull in friable varieties. Color cochineal-red, often inclining to brownish red and lead-gray. Streak scarlet. Transparent to opaque. Optically +. Indices: $\omega_r = 2{\cdot}854$, $\epsilon_r = 3{\cdot}201$, Dx. See Art. **366.**

Var.—1. *Ordinary:* either (*a*) *crystallized;* (*b*) *massive*, granular embedded or compact; bright red to reddish brown in color; (*c*) *earthy* and bright red. 2. *Hepatic.* Of a liver-brown color, with sometimes a brownish streak, occasionally slaty in structure, though commonly granular or compact.

Comp.—Mercuric sulphide, HgS = Sulphur 13·8, mercury 86·2 = 100. Usually impure from the admixture of clay, iron oxide, bitumen.

Pyr.—In the closed tube alone a black sublimate of mercuric sulphide, but with sodium carbonate one of metallic mercury. Carefully heated in the open tube gives sulphurous fumes and metallic mercury, which condenses in minute globules on the cold walls of the tube. B.B. on charcoal wholly volatile, but only when quite free from gangue.

Diff.—Characterized by its color and vermilion streak, high specific gravity (reduced, however, by the gangue usually present), softness; also by the blowpipe characters (*e.g.*, in the closed tube). Resembles some varieties of hematite and cuprite.

Obs.—Occurs chiefly in veins in slate rocks and shales, and rarely in granite or porphyry. It has been observed in veins, with ores of iron. Sometimes occurs in connection with hot springs as the result of solfataric action. Pyrite and marcasite, sulphides of copper, stibnite, realgar, gold, etc., are associated minerals; calcite, quartz or opal, also barite, fluorite, are gangue minerals; a bituminous mineral is common.

The most important European deposits are at Almaden in Spain, and at Idria in Carniola, where it is usually massive; also at Bakmut in southern Russia. Crystallized at Moschellandsberg and Wolfstein in the Palatinate and at the mines of Mt. Avala, near Belgrade, Servia; at Ripa in Tuscany; in the Urals; the Nerchinsk region in Transbaikal; in China; Japan; Mexico; Huancavelica, Peru; Chili.

In the U. S. forms extensive mines in California, the most important at New Almaden and the vicinity, in Santa Clara Co.; also at Altoona, Trinity Co.; it is now forming by solfataric action at Sulphur Bank, Cal., and Steamboat Springs, Nevada; also occurs in southern Utah.

The name cinnabar is supposed to come from India, where it is applied to the red resin, dragon's blood. The native cinnabar of Theophrastus is true cinnabar; he speaks of its affording quicksilver. The Latin name of cinnabar, *minium*, is now given to *red lead*, a substance which was early used for adulterating cinnabar, and so got at last the name.

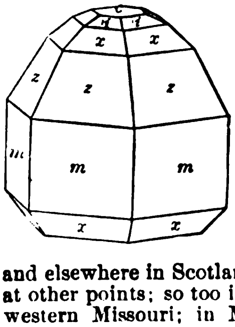
Covellite. Kupferindig *Germ.* Cupric sulphide, CuS. Rarely in hexagonal crystals. Commonly massive or spheroidal. G. = 4·59. Color indigo-blue or darker. From Badenweiler, Baden; Mansfeld, Thuringia; Vesuvius, on lava; Chili, etc.

GREENOCKITE.

Hexagonal-hemimorphic. Rarely in hemimorphic crystals; also as a coating.

Cleavage: *a* distinct, *c* imperfect. Fracture conchoidal. Brittle. H. = 3–3·5. G. = 4·9–5·0. Luster adamantine to resinous. Color honey-, citron-, or orange-yellow. Streak-powder between orange-yellow and brick-red. Nearly transparent. Optically +.

605.



Comp.—Cadmium sulphide, CdS = Sulphur 22·3, cadmium 77·7 = 100.

Pyr., etc.—In the closed tube assumes a carmine-red color while hot, fading to the original yellow on cooling. In the open tube gives sulphurous fumes. B.B. on charcoal, either alone or with soda, gives in R.F. a reddish-brown coating. Soluble in hydrochloric acid, affording hydrogen sulphide.

Obs.—Occurs with prehnite at Bishoptown, Renfrewshire, and elsewhere in Scotland. At Přibram in Bohemia, as a coating on sphalerite; similarly at other points; so too in the U. S. near Friedensville, Pa., and in the zinc region of southwestern Missouri; in Marion Co., Ark., it colors smithsonite bright yellow. Not uncommon as a furnace product.

Wurtzite. Zinc sulphide, ZnS, like sphalerite, but in hemimorphic hexagonal crystals; also fibrous and massive. G. = 3·98. Color brownish black. From a silver-mine near Oruro in Bolivia; Portugal; Peru. In crystals with sphalerite and quartz at the "Original Butte" mine, Butte City, Montana.

The massive fibrous forms of "Schalenblende" occur at Přibram, Liskeard, etc. Other forms, from Stolberg, Wiesloch, Altenberg, are in part wurtzite, in part sphalerite.

Erythrozincite is (Zn,Mn)S. From Siberia.

MILLERITE. Capillary Pyrites. Haarkies *Germ.*

Rhombohedral. Usually in very slender to capillary crystals, often in delicate radiating groups; sometimes interwoven like a wad of hair. Also in columnar tufted coatings, partly semi-globular and radiated.

Fracture uneven. Brittle; capillary crystals elastic. H. = 3–3·5. G. = 5·3–5·65. Luster metallic. Color brass-yellow, inclining to bronze-yellow, with often a gray iridescent tarnish. Streak greenish black.

Comp.—Nickel sulphide, NiS = Sulphur 35·3, nickel 64·7 = 100.

Pyr., etc.—In the open tube sulphurous fumes. B.B. on charcoal fuses to a globule. When roasted, gives with borax and salt of phosphorus a violet bead in O.F., becoming gray in R.F. from reduced metallic nickel. On charcoal in R.F. the roasted mineral gives a coherent metallic mass, attractable by the magnet. Most varieties also show traces of copper, cobalt, and iron with the fluxes.

Obs.—Occurs commonly in capillary crystals, in the cavities and among crystals of other minerals. Found at Joachimsthal in Bohemia; Johanngeorgenstadt; Přibram; Riechelsdorf; Andreasberg; Freiberg, Saxony; Cornwall.

In the U. S., at Antwerp, N. Y., in cavities in hematite; in Lancaster Co., Pa., at the Gap mine, in thin velvety coatings of a radiated fibrous structure. With calcite, dolomite and fluorite, forming delicate tangled hair-like tufts, in geodes in limestone, often penetrating the calcite crystals, at St. Louis, Mo.; similarly near Milwaukee, Wis. At Orford, Quebec.

Beyrichite. NiS like millerite with also Co,Fe. From Westerwald. The relation of the two species is doubtful.

Hauchecornite. Perhaps Ni(Bi,Sb,S). In tabular tetragonal crystals. H. = 5. G. = 6·4. Color light bronze-yellow. From Hamm a. d. Sieg.

NICCOLITE. Copper Nickel. Kupfernickel. Rothnickelkies *Germ.*

Hexagonal. Crystals rare. Usually massive, structure nearly impalpable; also reniform, columnar; reticulated, arborescent. Fracture uneven. Brittle. H. = 5–5·5. G. = 7·33–7·67. Luster metallic. Color pale copper-red. Streak pale brownish black. Opaque.

Comp.—Nickel arsenide, NiAs = Arsenic 56·1, nickel 43·9 = 100. Usually contains a little iron and cobalt, also sulphur; sometimes part of the arsenic is replaced by antimony, and then it graduates toward breithauptite. The intermediate varieties have been called *arite.*

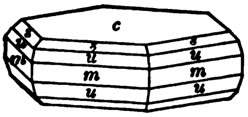
Pyr., etc.—In the closed tube a faint white crystalline sublimate of arsenic trioxide. In the open tube a sublimate of arsenic trioxide, with a trace of sulphurous fumes, the assay becoming yellowish green. On charcoal gives arsenical fumes and fuses to a globule, which, treated with borax glass, affords, by successive oxidation, reactions for iron, cobalt, and nickel; the antimonial varieties give also reactions for antimony. Soluble in aqua regia.

Obs.—Accompanies cobalt, silver, and copper ores in the Saxon mines of Annaberg, Schneeberg, etc.; also in Thuringia, Hesse, and Styria; at Allemont, Dauphiné; at the Ko mines in Nordmark, Sweden; at Balen in the Basses Pyrénées (*arite*); occasionally in Cornwall; Chili; abundant at Mina de la Rioja, Oriocha, Argentina. In the U. S., at Chatham, Conn., in gneiss; sparingly at Franklin Furnace, N. J.; Silver Cliff, Colorado; Tilt Cove, Newfoundland.

Breithauptite. Antimonnickel *Germ.* Nickel antimonide, NiSb. Rarely in hexagonal crystals; usually massive, arborescent, disseminated. G. = 7·54. Color light copper-red. From Andreasberg in the Harz.

PYRRHOTITE. Magnetic Pyrites. Magnetkies *Germ.*

606.



Hexagonal. $\dot{c} = 0{\cdot}8701$.

cs, $0001 \wedge 10\bar{1}1 = 45° \ 8'$.
cu, $0001 \wedge 40\bar{4}1 = 76° \ 0'$.
cy, $0001 \wedge (20{\cdot}0{\cdot}\bar{20}{\cdot}3) = 81° \ 30\tfrac{1}{2}'$.

Twins: tw. pl. *s*, with vertical axes nearly at right angles (Fig. 382, p. 125). Distinct crystals rare, commonly tabular; also acute pyramidal with faces striated horizontally. Usually massive, with granular structure.

Parting: *c*, sometimes distinct. Fracture uneven to subconchoidal. Brittle. H. = 3·5–4·5. G. = 4·58–4·64. Luster metallic. Color between bronze-yellow and copper-red, and subject to speedy tarnish. Streak dark grayish black. Magnetic, but varying much in intensity; sometimes possessing polarity.

Comp.—A sulphide of iron, often containing also nickel; formula chiefly $Fe_{11}S_{12}$; analyses, however, vary from Fe_5S_6 up to $Fe_{16}S_{17}$, while conforming to the general formula Fe_nS_{n+1}. Percentage composition $Fe_{11}S_{12}$ = Sulphur 38·4, iron 61·6 = 100; Fe_7S_8 = Sulphur 39·6, iron 60·4 = 100; Fe_8S_9 = Sulphur 39·2, iron = 60·8 = 100.

Pyr., etc.—Unchanged in the closed tube. In the open tube gives sulphurous fumes. On charcoal in R.F. fuses to a black magnetic mass; in O.F. is converted into red oxide, which with fluxes gives only an iron reaction when pure, but many varieties yield small amounts of nickel and cobalt. Decomposed by hydrochloric acid, with evolution of hydrogen sulphide.

Diff.—Distinguished by its peculiar reddish-bronze color; also by its magnetic properties.

Obs.—Occurs at Kongsberg, Modum, etc., in Norway; Falun, Sweden; Andreasberg; Bodenmais; Breitenbrunn; Joachimsthal, Bohemia; Nizhni Tagilsk; Minas Geraes in Brazil, in large tabular crystals; the lavas of Vesuvius; Cornwall.

In N. America in *Maine*, at Standish with andalusite; in *Vermont*, at Stafford, etc. In *N. York*, near Diana, Lewis Co.; Orange Co. In *Pennsylvania*, at the Gap mine, Lancaster Co., nickeliferous. In *Tennessee*, at Ducktown mines, abundant. In Canada, in large veins at St. Jérôme, Elizabethtown, Ontario; at Sudbury, etc. This species is often mined for the nickel it contains.

Pyrrhotite is often present in disseminated particles or crystals in meteoric stones; the iron sulphide of meteoric irons is generally referred to troilite (p. 293).

Named from πυῤῥότης, *reddish.*

C. Intermediate Division.

Horbachite. An iron-nickel sulphide, perhaps $4Fe_2S_3.Ni_2S_3$. Crystalline, massive. Color pinchbeck-brown to steel-gray. G. = 4·43. From Horbach in the Black Forest.

Polydymite. A nickel sulphide, perhaps Ni_4S_5. In octahedral crystals; frequently twinned. G. = 4·54–4·81. Color gray. From Grünau, Westphalia.

A nickel ore from Sudbury, Ontario, corresponds to Ni_3FeS_5, conforming to the general formula of polydymite; another Sudbury ore agrees with pentlandite (p. 293), and still another is a nickeliferous pyrrhotite.

Grünauite. Contains sulphur, bismuth, nickel, iron; perhaps a mixture. From Grünau.

Sychnodymite. Essentially $(Co,Cu)_4S_5$. Isometric, in small steel-gray octahedrons. From the Siegen district, Germany.

Melonite. Tellurnickel *Germ.* A nickel telluride, Ni_2Te_3. In indistinct granular and foliated particles. Color reddish white, with metallic luster. From the Stanislaus mine, California; probably also in Boulder Co., Colorado.

The following species are sometimes regarded as Sulpho-salts, namely, Sulpho-ferrites, etc.

BORNITE. Buntkupfererz *Germ.* Purple Copper Ore. Variegated Copper Ore. Erubescite.

Isometric. Habit cubic, faces often rough or curved. Twins: tw. pl. *o*, often penetration-twins. Massive, structure granular or compact.

Cleavage: *o* in traces. Fracture small conchoidal, uneven. Brittle. H. = 3. G. = 4·9–5·4. Luster metallic. Color between copper-red and pinchbeck-brown on fresh fracture, speedily iridescent from tarnish. Streak pale grayish black. Opaque.

Comp., Var.—A sulphide of copper and iron, but varying in the proportions of these metals. The crystallized mineral agrees with Cu_3FeS_3 = Sulphur 28·1, copper 55·5, iron 16·4 = 100: this may be written $3Cu_2S.Fe_2S_3$ (Groth) or $Cu_2S.CuS.FeS$ (Rg.).

Analyses of massive varieties give from 50 to 70 p. c. of copper and 15 to 6·5 p. c. of iron. The variation is due, in part at least, to mechanical admixture, chiefly of chalcocite.

Pyr., etc.—In the closed tube gives a faint sublimate of sulphur. In the open tube yields sulphurous fumes, but no sublimate. B.B. on charcoal fuses in R.F. to a brittle magnetic globule. The roasted mineral gives with the fluxes the reactions of iron and copper, and with soda a metallic globule. Soluble in nitric acid with separation of sulphur.

Diff.—Distinguished (*e.g.* from chalcocite) by the peculiar reddish color on the fresh fracture and by its brilliant tarnish; B.B. becomes strongly magnetic.

Obs.—Occurs with other copper ores, and is a valuable ore of copper. Crystalline varieties are found in Cornwall, called by the miners "horse-flesh ore." Occurs massive at Ross Island, Killarney, Ireland; Monte Catini, Tuscany; the Mansfeld district, Germany; in Norway, Sweden, Siberia, Silesia, and Hungary. It is the principal copper ore at some Chilian mines; also common in Peru, Bolivia, and Mexico.

In the U. S., found at the copper mine in Bristol, Conn.; massive at Mahoopeny, near Wilkesbarre, Penn. A common ore in Canada, at the Acton and other mines.

Named after the mineralogist Ignatius von Born (1742–1791).

Linnæite. A sulphide of cobalt, $Co_3S_4 = CoS.Co_2S_3$, analogous to the spinel group. Also contains nickel (var. *siegenite*). Commonly in octahedrons; also massive. H. = 5·5. G. = 4·8–5. Color pale steel-gray, tarnishing copper-red. Occurs at Bastnaes, etc., Sweden; Müsen, near Siegen, Prussia; at Siegen (*siegenite*), in octahedrons. In the U. S., at Mine la Motte, Missouri; Mineral Hill, Maryland.

Daubréelite. An iron-chromium sulphide, $FeS.Cr_2S_3$, occurring with troilite in some meteoric irons. Color black. G. = 5·01.

Cubanite. An iron-copper sulphide, perhaps $CuFe_2S_4 = CuS.Fe_2S_3$. Isometric; massive. Color between bronze- and brass-yellow. G. = 4·03–4·17. From Barracanao, Cuba; Tunaberg and Kafveltorp, Sweden.

Carrollite. A copper-cobalt sulphide, $CuCo_2S_4 = CuS.Co_2S_3$. Isometric; rarely in octahedrons. Usually massive. G. = 4·85. Color light steel-gray, with a faint reddish hue. From Carroll Co., Maryland, near Finksburg.

CHALCOPYRITE. Copper Pyrites. Yellow Copper Ore. Kupferkies *Germ.*

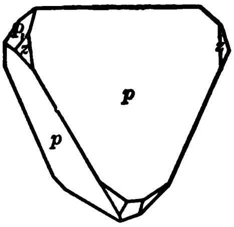
Tetragonal-sphenoidal. Axis $\dot{c} = 0{\cdot}98525$.

pp', $111 \wedge \bar{1}\bar{1}1 = 108° 40'$. $pp_,$, $111 \wedge 1\bar{1}1 = 70° 7\frac{1}{2}'$. ce, $001 \wedge 101 = 45° 34\frac{1}{2}'$.

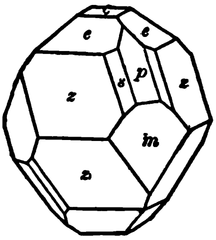
Crystals commonly tetrahedral in aspect, the sphenoidal faces *p* large, dull or oxidized; $p_,$ small and brilliant. Sometimes both forms equally developed, and then octahedral in form. Twins: (1) tw. pl. *p* (111), resembling spinel-twins (Fig. 379, p. 125); sometimes repeated as a fiveling (Fig. 609). (2) Tw. pl. and comp.-face *e* (Fig. 381, p. 125) often in repeated twins. (3) Tw. pl. *m*, tw. axis *c*, complementary penetration-twins. Often massive, compact.

Cleavage: *z* (201), sometimes distinct; *c*, indistinct. Fracture uneven. Brittle. H. = 3·5–4. G. = 4·1–4·3. Luster metallic. Color brass-yellow; often tarnished or iridescent. Streak greenish black. Opaque.

607.

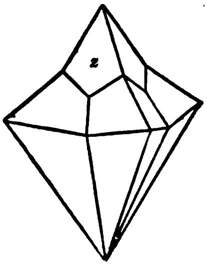


608.



z (201), *s* (518).

609.



Comp.—A sulphide of copper and iron, $CuFeS_2$ or $Cu_2S.Fe_2S_3$ = Sulphur 35·0, copper 34·5, iron 30·5 = 100. Analyses often show variations from this formula, often due to mechanical admixture of pyrite.

Sometimes auriferous and argentiferous; also contains traces of selenium and thallium.

Pyr., etc.—In the closed tube decrepitates, and gives a sulphur sublimate, in the open tube sulphurous fumes. On charcoal fuses to a magnetic globule; with soda the roasted mineral gives a globule of copper containing iron. The roasted mineral reacts for copper and iron with the fluxes. Dissolves in nitric acid, excepting the sulphur, and forms a green solution; ammonia in excess changes the green color to a deep blue, and precipitates red ferric hydroxide.

Diff.—Distinguished from pyrite by its inferior hardness and deeper yellow color. Resembles gold when disseminated in minute grains in quartz, but differs in being brittle and in having a black streak; further it is soluble in nitric acid.

Obs.—A widely disseminated mineral in metallic veins and nests in gneiss and crystalline schists, also in serpentine rocks; often intimately associated with pyrite, also with siderite, tetrahedrite, etc., sometimes with nickel and cobalt sulphides, pyrrhotite, etc. Observed coated with tetrahedrite crystals in parallel position, also as a coating over the latter.

Chalcopyrite is the principal ore of copper at the Cornwall mines; there associated with cassiterite, galena, bornite, chalcocite, tetrahedrite, sphalerite. At Falun, Sweden, it occurs in large masses embedded in gneiss. At Rammelsberg, near Goslar in the Harz, forms a bed in argillaceous schist; occurs with nickel and cobalt ores in the Kupferschiefer of Mansfeld. The Kurprinz mine at Freiberg affords well-defined crystals; also Horhausen, Dillenburg, Neudorf, Müsen; Schlackenwald in Bohemia. Common elsewhere as at Mte. Catini in Tuscany; in New South Wales; Chili, etc.

In *Maine*, at the Lubec mines and elsewhere. In *Vermont*, at Stafford, etc. In *Mass.*, at the Southampton lead mines. In *Conn.*, at Bristol. In *New York*, in crystals and massive at Ellenville, Ulster Co. In *Pennsylvania*, at Phenixville; at the French Creek mines, Chester Co., with pyrite, magnetite, etc. In *Maryland*, near Finksbury, Carroll Co., abundant. In *Virginia*, at the Phenix copper mines, Fauquier Co., and the Walton gold mine, Louisa Co. In *N. Carolina*, near Greensboro', abundant massive. In *Tennessee*, 30 miles from Cleveland, in Polk Co. In *Missouri*, with sphalerite at Joplin, Jasper Co.

In *Cal.*, in different mines along a belt between Mariposa Co. and Del Norte Co., on west side of, and parallel to, the chief gold belt; occurring massive in Calaveras Co., and in crystals on Domingo Creek, etc. Abundant in *Montana*, near Butte, with bornite, pyrite, etc., also at other points, often argentiferous and auriferous. In *Colorado*, abundant in Gilpin, Boulder, Chaffee, Gunnison counties, etc.; commonly associated with pyrite, tetrahedrite, sphalerite, and often highly argentiferous. Also mined in Arizona, Utah, but in most cases chiefly for silver and gold. Grant Co., New Mexico.

In *Canada*, in Perth and near Sherbrooke and at many points in the eastern part of the province of Quebec; in the Nipissing distr., Ontario, at various points; extensively mined at Sudbury; at the Bruce mines, on Lake Huron; at Point-au-Mines and elsewhere on Lake Superior.

Named from *χαλκός, brass*, and *pyrites*, by Henckel (1725).

D. Disulphides, Diarsenides, etc.

The disulphides, diarsenides, etc., embrace two distinct groups. The prominent metals included are the same in both, viz.: iron, cobalt and nickel. The groups present, therefore, several cases of isodimorphism, as is shown in the lists of species below. These sulphides are all relatively *hard*, H. = 5–6; they hence strike fire with a steel, and this has given the familiar name *pyrites* applied to most of them. The color varies between pale brass-yellow and tin-white.

Pyrite Group. RS_2, RAs_2, RSb_2. Isometric-pyritohedral.

Pyrite	FeS_2	**Gersdorffite**	$NiS_2.NiAs_2$
Hauerite	MnS_2	**Corynite**	$NiS_2.Ni(As,Sb)_2$
Smaltite	$CoAs_2$, also $(Co,Ni)As_2$	**Ullmannite**	$NiS_2.NiSb_2$ (isometric-tetartohedral)
Chloanthite	$NiAs_2$, also $(Ni,Co)As_2$	**Sperrylite**	$PtAs_2$
Cobaltite	$CoS_2.CoAs_2$	**Laurite**	RuS_2?

Marcasite Group. RS_2, RAs_2, etc. Orthorhombic.

		$\breve{a} : b : \dot{c}$	$110 \wedge 1\bar{1}0$	$101 \wedge \bar{1}01$
Marcasite	FeS_2	0·7662 : 1 : 1·2342	74° 55′	116° 20′
Löllingite	$FeAs_2$	0·6689 : 1 : 1·2331	67° 33′	123° 3′
Leucopyrite	Fe_3As_4			
Arsenopyrite	$FeS_2.FeAs_2$	0·6773 : 1 : 1·1882	68° 13′	120° 38′
Danaite	$(Fe,Co)S_2.(Fe,Co)As_2$			
Safflorite	$CoAs_2$			
Rammelsbergite	$NiAs_2$			
Glaucodot	$(Co,Fe)S_2.(CoFe)As_2$	0·6942 : 1 : 1·1925	69° 32′	119° 35′
Alloclasite	$(Co,Fe)(As,Bi)S$			
Wolfachite	$NiS_2.Ni(As,Sb)_2$			

The PYRITE GROUP includes besides the compounds of Fe, Co, Ni, also others of the related metals Mn and Pt. The crystallization is isometric-pyritohedral.

The species of the MARCASITE GROUP crystallize in the orthorhombic system with prismatic angles of about 70° and 110° and a prominent macrodome of about 60° and 120°. Hence fivefold and sixfold repeated twins are common with several species, in the one case the prism and in the other the macrodome named being the twinning-plane.

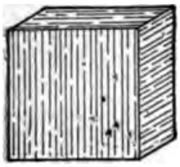
Pyrite Group.

PYRITE. Schwefelkies, Eisenkies, *Germ.* Iron Pyrites.

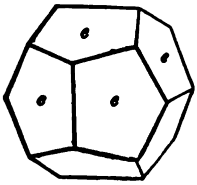
Isometric-pyritohedral. Cube and pyritohedron *e* (210) the common forms, the faces of both often with striations ‖ edge *a*/*e*, due to oscillatory combination of these forms and tending to produce rounded faces; pyritohedral faces also striated ⊥ to this edge; octahedron also common. See Figs. 610–617, also Figs. 117–123, pp. 44, 45. Twins: tw. ax *a*, usually penetration-twins with parallel axes (Fig. 369, p. 124); rarely contact-twins. Frequently massive, fine granular; sometimes subfibrous radiated; reniform, globular, stalactitic.

Cleavage: *a*, *o* indistinct. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 4·95–5·10; 4·967 Traversella, 5·027 Elba. Luster metallic, splendent to glistening. Color a pale brass-yellow, nearly uniform. Streak greenish black or brownish black. Opaque.

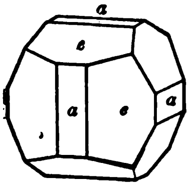
610.



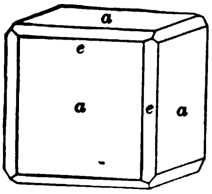
611.



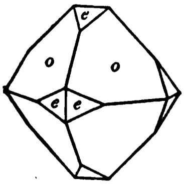
612.



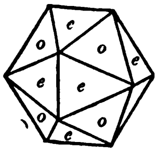
613.



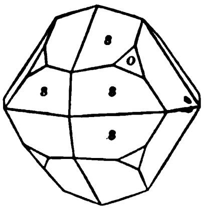
614.



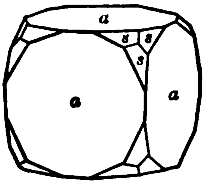
615.



616.



617.



Comp., Var.—Iron disulphide, FeS_2 = Sulphur 53·4, iron 46·6 = 100.

Nickel, cobalt, and thallium, and also copper in small quantities, sometimes replace part of the iron, or else occur as mixtures; selenium is sometimes present in traces. Gold is sometimes distributed invisibly through it, auriferous pyrite being an important source of gold. Arsenic is rarely present, as in octahedral crystals from French Creek, Penn. (0·2 p. c. As).

Pyr., etc.—In the closed tube a sublimate of sulphur and a magnetic residue. B.B. on charcoal gives off sulphur, burning with a blue flame, leaving a magnetic residue which reacts like pyrrhotite (p. 296). Insoluble in hydrochloric, but decomposed by nitric acid.

Diff.—Distinguished from chalcopyrite by its greater hardness and paler color; in form and specific gravity different from marcasite, which has also a whiter color.

Obs.—Pyrite occurs abundantly in rocks of all ages, from the oldest crystalline to the most recent alluvial deposits. It usually occurs in small cubes, pyritohedrons, or in more highly modified forms; also (often with marcasite) in irregular spheroidal nodules and in veins, in clay slate, argillaceous sandstones, the coal formation, etc.

Fine crystals have been found in some of the Cornish mines; also in great variety with hematite on the island of Elba, and with magnetite at Traversella and Brosso in Piedmont. Other localities for crystals are Müsen near Siegen; Freiberg, Saxony; Schneeberg; Waldenstein in Carinthia; Přibram, Bohemia; Schemnitz, Hungary; Persberg, Falun, and Långban in Sweden; Kongsberg in Norway.

In *Maine*, at Peru, Waterville, etc. In *N. Hampshire*, at Unity, massive. In *Mass.*, at Rowe, Hawley, massive. In *Vermont*, at Shoreham, in limestone; Hartford. In *Conn.*, at Roxbury, finely crystallized. In *N. York*, at Rossie, fine crystals; at Schoharie; at Chester, Warren Co.; in Orange Co., at Warwick; massive in Franklin, Putnam, and Orange Cos., etc. In *Pennsylvania*, at Chester, Delaware Co.; at Knauertown, Chester Co.; at French Creek mines, octahedrons and other forms, sometimes tetragonal or orthorhombic in symmetry; Cornwall, Lebanon Co.; in *N. Car.*, near Greensboro', Guilford Co., in crystals. In *Colorado*, crystals near Central City, Gilpin Co., and elsewhere. Auriferous pyrite is common at the mines of Colorado, and many of those of California, as well as in Virginia and the States south. In *Canada*, 2 miles N. W. of Brockville, Ontario, a cobaltiferous variety.

Large quantities of massive pyrite are mined at the Rio Tinto and other mines in Spain, also in Portugal. Among important deposits in the U. S. are those at Rowe, Mass.; Herman, St. Lawrence Co., and Ellenville, Ulster Co., N. Y.; Tolersville, Louisa Co., Va.; Dallas, Paulding Co., Ga.

The name *pyrite* is derived from πῦρ, *fire*, and alludes to the sparks from friction; hence the early name *pyrites* (p. 299).

Pyrite readily changes to an iron sulphate by oxidation, some sulphur being set free. Also to limonite on its surface, and afterward throughout, by the action of a solution of bicarbonate of lime carrying off the sulphuric acid as change proceeds, and from limonite to red iron oxide.

Hauerite. Manganese disulphide, MnS_2. In octahedral or pyritohedral crystals; also massive. G. = 3·46. Color reddish brown or brownish black. From Kalinka, Hungary; Raddusa, Catania, Sicily.

SMALTITE-CHLOANTHITE. Speiskobalt *Germ.*

Isometric-pyritohedral. Commonly massive; in reticulated and other imitative shapes.

Cleavage: *o* distinct; *a* in traces. Fracture granular and uneven. Brittle. H. = 5·5–6. G. = 6·4 to 6·6. Luster metallic. Color tin-white, inclining, when massive, to steel-gray, sometimes iridescent, or grayish from tarnish. Streak grayish black. Opaque.

Comp.—SMALTITE is essentially cobalt diarsenide, $CoAs_2$ = Arsenic 71·8, cobalt 28·2 = 100. CHLOANTHITE is nickel diarsenide, $NiAs_2$ = Arsenic 71·9, nickel 28·1 = 100.

Cobalt and nickel are usually both present, and thus these two species graduate into each other, and no sharp line can be drawn between them. Iron is also present in varying amount; the variety of chloanthite containing much iron has been called *chathamite*. Further sulphur is usually present, but only in small quantities. Many analyses do not conform even approximately to the formula RAs_2, the ratio rising from less than 1 : 2 to 1 : 2·5 and nearly 1 : 3, thus showing a tendency toward skutterudite (RAs_3), perhaps due to either molecular or mechanical mixture.

Much that has been called smaltite (speiskobalt) is shown by the high specific gravity to belong to the orthorhombic species safflorite.

Pyr., etc.—In the closed tube gives a sublimate of metallic arsenic; in the open tube a white sublimate of arsenic trioxide, and sometimes traces of sulphur dioxide. B.B. on charcoal gives an arsenical odor, and fuses to a globule, which, treated with successive portions of borax-glass, affords reactions for iron, cobalt, and nickel.

Obs.—Usually occurs in veins, accompanying ores of cobalt or nickel, and ores of silver and copper; also, in some instances, with niccolite and arsenopyrite. Found at the Saxon mines; Joachimsthal, Bohemia; Wheal Sparnon, Cornwall; Riechelsdorf, Hesse; Tunaberg, Sweden; Allemont, Dauphiné. In the U. S., at Chatham, Conn., the *chathamite* occurs in mica slate, with arsenopyrite and niccolite; at Franklin Furnace, N. J.

COBALTITE.

Isometric-pyritohedral. Commonly in cubes, or pyritohedrons, or combinations resembling common forms of pyrite. Also granular massive to compact.

Cleavage: cubic, rather perfect. Fracture uneven. Brittle. H. = 5·5. G. = 6–6·3. Luster metallic. Color silver-white, inclined to red; also steel-gray, with a violet tinge, or grayish black when containing much iron. Streak grayish black.

Comp.—Sulpharsenide of cobalt, CoAsS or $CoS_2.CoAs_2$ = Sulphur 19·3, arsenic 45·2, cobalt 35·5 = 100.

Iron is present, and in the variety *ferrocobaltite* in large amount.

Pyr., etc.—Unaltered in the closed tube. In the open tube gives sulphurous fumes, and a crystalline sublimate of arsenic trioxide. B.B. on charcoal gives off sulphur and arsenic, and fuses to a magnetic globule; with borax a cobalt-blue color. Soluble in warm nitric acid, with the separation of sulphur.

Obs.—Occurs at Tunaberg and Hakansbö in Sweden; at the Nordmark mines; also at Skutterud in Norway; at Schladming, Styria; Siegen in Westphalia; Botallack mine, near St. Just, in Cornwall; Khetri mines, Rajputana, India.

Gersdorffite. Sulpharsenide of nickel, NiAsS or $NiS_2.NiAs_2$. Iron, and sometimes cobalt, replace more or less of the nickel. Isometric-pyritohedral; usually massive. H. = 5·5. G. = 5·6–6·2. Color silver-white to steel-gray. From Loos, Sweden; the Harz; Schladming, Styria, etc.

Corynite is near gersdorffite, but contains also antimony. From Olsa, Carinthia.

Willyamite. $CoS_2.NiS_2CoSb_2.NiSb_2$. Cleavage cubic. Color tin-white to steel-gray. Broken Hill mines, New South Wales.

Ullmannite. Sulphantimonide of nickel, NiSbS or $NiS_2.NiSb_2$; arsenic is usually present in small amount. Isometric-tetartohedral; both pyritohedral and tetrahedral forms occur (see Figs. 146, 147, p. 51). Usually massive, granular. H. = 5–5·5. G. = 6·2–6·7. Color steel-gray to silver-white. Occurs in the mines of Freusburg, Nassau; Siegen, Prussia; Lölling, Carinthia (tetrahedral); Montenarba, Sarrabus, Sardinia (pyritohedral).

KALLILITE. Wismuthantimonnickelglanz *Germ.* Ni(Sb,Bi)S or $NiS_2.Ni(Sb,Bi)_2$. Massive, color light bluish gray. From the Friedrich mine near Schönstein a. d. Sieg, Germany.

Sperrylite. Platinum diarsenide, $PtAs_2$. In minute cubes, or cubo-octahedrons. H. = 6–7. G. = 10·602. Luster metallic. Color tin-white. Streak black. Found at the Vermillion mine, 22 miles west of Sudbury, Ontario, Canada; also in Macon Co., N. Carolina. This is the only known native compound of platinum.

Laurite. Sulphide of ruthenium and osmium, probably essentially RuS_2. In minute octahedrons; in grains. H. = 7·5. G. = 6·99. Luster metallic. Color dark iron-black. From the platinum washings of Borneo. Also reported from Oregon.

Skutterudite. Cobalt arsenide, $CoAs_3$. Isometric-pyritohedral. Also massive granular. Cleavage: *a* distinct. H. = 6. G. = 6·72–6·86. Color between tin-white and pale lead-gray. From Skutterud, Norway.

NICKEL-SKUTTERUDITE. $(Ni,Co,Fe)As_3$. Massive, granular. Color gray. From near Silver City, New Mexico.

BISMUTO-SMALTITE. $Co(As,Bi)_3$. A skutterudite containing bismuth. Color tin-white. G. = 6·92. Zschorlau, near Schneeberg.

Marcasite Group.

For the list of species and their relations, see p. 299.

MARCASITE. White iron pyrites.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}7662 : 1 : 1{\cdot}2342$.

mm''', $110 \wedge 1\bar{1}0 = 74° 55'$. ll', $011 \wedge 0\bar{1}1 = 101° 58'$.
ee', $101 \wedge \bar{1}01 = 116° 20'$. cs, $001 \wedge 111 = 63° 46'$.

Twins: tw. pl. *m* (Fig. 619), sometimes in stellate fivelings (Fig. 406, p. 128, cf. Fig. 620); also tw. pl. *e* (101), less common the crystals crossing at angles of nearly 60°. Crystals commonly tabular ‖ *c*, also pyramidal; the brachydomes striated ‖ edge *b*/*c*. Often massive; in stalactites; also globular, reniform, and other imitative shapes.

Cleavage: *m* rather distinct; *l* (011) in traces. Fracture uneven. Brittle. H. = 6–6·5. G. = 4·85–4·90. Luster metallic. Color pale bronze-yellow, deepening on exposure. Streak grayish or brownish black. Opaque.

Comp.—Iron disulphide, like pyrite, FeS_2 = Sulphur 53·4, iron 46·6 = 100. Arsenic is sometimes present in small amount.

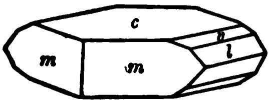
Var.—The varieties named depend mainly on state of crystallization. *Radiated* (*Strahlkies* Germ.): Radiated; also the simple crystals. *Cockscomb P.* (*Kammkies* Germ.): Aggregations of flattened twin crystals in crest-like forms. *Spear P.* (*Speerkies* Germ.): Twin crystals, with re-entering angles a little like the head of a spear in form. *Capillary* (*Haarkies* Germ.): In capillary crystallizations.

Pyr., etc.—Like pyrite. Very liable to decomposition, more so than pyrite.

Diff.—Resembles pyrite, but has a lower specific gravity, and the color when fresh (*e.g.* after treatment with acid) is paler; when crystallized easily distinguished by the forms. More subject to tarnish and final decomposition than pyrite.

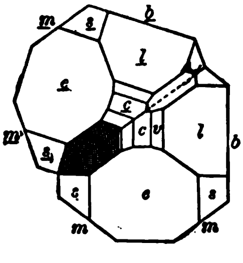
Obs.—Occurs abundantly at Littmitz and Altsattell, near Carlsbad in Bohemia; also at Joachimsthal, Bohemia, and in Saxony and the Harz. Occurs with galena and fluorite in Derbyshire; in chalk-marl between Folkestone and Dover; near Alston Moor, Cumberland; Schemnitz, Hungary. At Warwick, N. Y., in crystals; massive at Cummington, Mass., and at Lane's mine, Monroe, Conn.; at Galena, Ill., in stalactites with concentric layers of sphalerite and galena; Mineral Point, Wis., in fine crystals; on sphalerite at Joplin, Mo.

618.



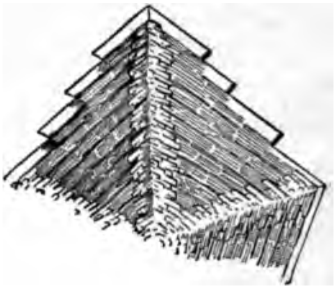
Common Form.

619.



Galena, Ill.

620.



Folkestone.

The word *marcasite*, of Arabic or Moorish origin (and variously used by old writers, for bismuth, antimony), was the name of common crystallized pyrite among miners and mineralogists in later centuries, until near the close of the last. It was first given to this species by Haidinger in 1845.

Löllingite. Essentially iron diarsenide, $FeAs_2$, but passing into Fe_3As_4 (*leucopyrite*); also tending toward arsenopyrite (FeAsS) and safflorite ($CoAs_2$). Bismuth and antimony are sometimes present. Usually massive. H. = 5–5·5. G. = 7·0–7·4 chiefly, also 6·8. Luster metallic. Color between silver-white and steel-gray. Streak grayish black. Occurs in the Lölling-Hüttenberg district in Carinthia; with niccolite at Schladming, etc. In the U. S., löllingite occurs in Gunnison Co., Colorado, etc.

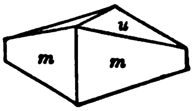
GEYERITE is near löllingite, but contains sulphur; from Geyer, Saxony.

ARSENOPYRITE, or MISPICKEL. Arsenkies *Germ.*

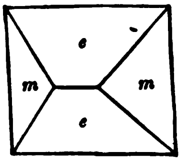
Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·6773 : 1 : 1·1882.

mm''', 110 ∧ $1\bar{1}0$ = 68° 13′.
ee', 101 ∧ $\bar{1}01$ = 120° 38′.
uu', 014 ∧ $0\bar{1}4$ = 33° 5′.
nn', 012 ∧ $0\bar{1}2$ = 61° 26′.
qq', 011 ∧ $0\bar{1}1$ = 99° 50′.

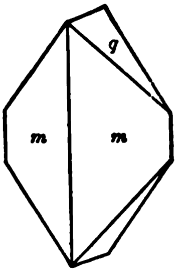
621.



622.



623.



Twins: tw. pl. *m*, sometimes repeated like marcasite (Fig. 407, p. 128); *e* (101) cruciform twins, also trillings (Figs. 402, 403, p. 128). Crystals prismatic *m*, or flattened vertically by the oscillatory combination of brachydomes. Also columnar, straight, and divergent; granular, or compact.

Cleavage: *m* rather distinct; *c* in faint traces. Fracture uneven. Brittle.

H. = 5·5–6. G. = 5·9–6·2. Luster metallic. Color silver-white, inclining to steel-gray. Streak dark grayish black. Opaque.

Comp., Var.—Sulpharsenide of iron, FeAsS or $FeS_2.FeAs_2$ = Arsenic 46·0, sulphur 19·7, iron 34·3 = 100. Part of the iron is sometimes replaced by cobalt, as in the variety *danaite* (3 to 9 p. c. Co).

Pyr., etc.—In the closed tube at first gives a red sublimate of arsenic trisulphide, then a black lustrous sublimate of metallic arsenic. In the open tube gives sulphurous fumes and a white sublimate of arsenic trioxide. B.B. on charcoal gives arsenical fumes and a magnetic globule. The varieties containing cobalt give, after the arsenic has been roasted off, a blue color with borax-glass when fused in O.F. with successive portions of flux until all the iron is oxidized. Gives fire with steel, emitting an alliaceous odor. Decomposed by nitric acid with the separation of sulphur.

Diff.—Characterized by its hardness and tin-white color; closely resembles some of the sulphides and arsenides of cobalt and nickel, but identified, in most cases easily, by its blowpipe characters. Löllingite does not give a decided sulphur reaction.

Obs.—Found principally in crystalline rocks, its usual mineral associates being ores of silver, lead, and tin, also pyrite, chalcopyrite, and sphalerite. Abundant at Freiberg, etc., in Saxony; Reichenstein, Silesia, in serpentine; in beds at Breitenbrunn, Andreasberg, Joachimsthal; Tunaberg, Sweden; Skutterud, Norway; at several points in Cornwall.

In the U. S., in *N. Hampshire*, in gneiss, at Franconia (*danaite*). In *Maine*, at Blue Hill, etc. In *Conn.*, at Chatham; at Mine Hill, Roxbury, with siderite. In *N. York*, massive, in Lewis, Essex Co., with hornblende; near Edenville, and elsewhere in Orange Co. In *California*, Nevada Co., Grass valley. In crystals at St. François, Beauce Co., Quebec; large beds occur in quartz ore veins at Deloro, Hastings Co., Ontario, where it is mined for gold.

The name mispickel is an old German term of doubtful origin. *Danaite* is from J. Freeman Dana of Boston (1798–1827), who made known the Franconia locality.

Safflorite. Like smaltite, essentially cobalt diarsenide, $CoAs_2$. Form near that of arsenopyrite. Usually massive. H. = 4·5–5. G. = 6·9–7·3. Color tin-white, soon tarnishing. From Schneeberg, Saxony; Bieber, Hesse; Wittichen, Baden; Tunaberg, Sweden.

Rammelsbergite. Essentially nickel diarsenide, $NiAs_2$, like chloanthite. Crystals resembling arsenopyrite; also massive. G. = 6·9–7·2. Color tin-white with tinge of red. Occurs at Schneeberg and at Riechelsdorf.

Glaucodot. Sulpharsenide of cobalt and iron, (Co,Fe)AsS. In orthorhombic crystals (axes, etc., p. 299). Also massive. H. = 5. G. = 5·90–6·01. Luster metallic. Color grayish tin-white. Occurs in the province of Huasco, Chili; at Hakansbö, Sweden. Named from γλαυκός, *blue*, because used for making smalt.

Alloclasite. Probably essentially Co(As,Bi)S with cobalt in part replaced by iron; or a glaucodot containing bismuth. Commonly in columnar to hemispherical aggregates. H. = 4·5. G. = 6·6. Color steel-gray. From Orawitza.

Wolfachite. Probably Ni(As,Sb)S, near corynite. In small crystals resembling arsenopyrite; also columnar radiated. H. = 4·5–5. G. = 6·372. Color silver-white to tin-white. From Wolfach, Baden.

The following species are tellurides of gold, silver, etc.

SYLVANITE. Graphic Tellurium. Schrift-Tellur *Germ.*

Monoclinic. $\grave{a} : \bar{b} : \dot{c} = 1.6339 : 1 : 1.1265$; $\beta = 89° 35'$. Often in branching arborescent forms resembling written characters; also bladed and imperfectly columnar to granular.

Cleavage: *b* perfect. Fracture uneven. Brittle. H. = 1·5–2. G. = 7·9–8·3. Luster metallic, brilliant. Color and streak pure steel-gray to silver-white, inclining to yellow.

Comp.—Telluride of gold and silver $(Au,Ag)Te_2$ with Au : Ag = 1 : 1; this requires: Tellurium 62·1, gold 24·5, silver 13·4 = 100.

Pyr., etc.—In the open tube gives a white sublimate of tellurium dioxide which near the assay is gray; when treated with the blowpipe flame the sublimate fuses to clear transparent drops. B.B. on charcoal fuses to a dark gray globule, covering the coal with a white coating, which treated in R.F. disappears, giving a bluish-green color to the flame; after long blowing a yellow, malleable metallic globule is obtained. Most varieties give a faint coating of lead oxide and antimony oxide on charcoal.

Obs.—With gold, at Offenbánya, Transylvania; also at Nagyág. In California, Calaveras Co., at the Melones and Stanislaus mines. In Boulder Co., and elsewhere in Colorado. Named from Transylvania, where first found, and in allusion to *sylvanium*, one of the names at first proposed for the metal tellurium.

Krennerite. A telluride of gold and silver $(Au,Ag)Te_2$ like sylvanite. In prismatic crystals (orthorhombic), vertically striated. G. = 8·353. Color silver-white to brass-yellow. From Nagyág, Transylvania; Cripple Creek Colorado.

CALAVERITE. A gold-silver telluride. Like sylvanite $(Au,Ag)Te_2$ with Au : Ag = 6 : 1 or 7 : 1. Massive. H. = 2·5. G. = 9·043. Color pale bronze-yellow. Occurs with petzite at the Stanislaus mine, Calaveras county, California. Also at the Red Cloud and other mines, Colorado.

Calaverite has the same general formula as sylvanite but a much higher percentage of gold, and may belong with it; or, as seems probable, krennerite may be the crystallized form of calaverite.

Nagyagite. A sulpho-telluride of lead and gold; containing also about 7 p. c. of antimony. Orthorhombic. Crystals tabular ∥ *b*; also granular massive, foliated. Cleavage: *b* perfect; flexible. H. = 1-1·5. G. = 6·85-7·2. Luster metallic, splendent. Streak and color blackish lead-gray. Opaque. From Nagyág, Transylvania; and at Offenbánya. Reported from Colorado.

Oxysulphides.

Here are included Kermesite, Sb_2S_2O, and Voltzite, Zn_5S_4O.

Kermesite. Antimonblende, Rothspiessglanzerz *Germ.* Pyrostibite. Antimony oxysulphide, Sb_2S_2O or $2Sb_2S_3.Sb_2O_3$. Monoclinic. Usually in tufts of capillary crystals. Cleavage: *a* perfect. H. = 1-1·5. G. = 4·5-4·6. Luster adamantine. Color cherry-red.

Results from the alteration of stibnite. Occurs at Malaczka, Hungary; Bräunsdorf, Saxony; Allemont, Dauphiné. At South Ham, Wolfe Co., Quebec, Canada; with native antimony and stibnite at the Prince William mine, York Co., New Brunswick.

Named from *kermes*, a name given (from the Persian *qurmizq*, crimson) in the older chemistry to red amorphous antimony trisulphide, often mixed with antimony trioxide.

Voltzite. Zinc oxysulphide, Zn_5S_4O or $4ZnS.ZnO$. In implanted spherical globules; H. = 4-4·5. G. = 3·66-3·80. Color dirty rose-red, yellowish. Occurs at Rosières, Puy de Dôme; Joachimsthal; Marienberg, Saxony (*leberblende*).

III. SULPHO-SALTS.

I. Sulpharsenites, Sulphantimonites, Sulphobismuthites.

II. Sulpharsenates, Sulphostannates, etc.

I. Sulpharsenites, Sulphantimonites, etc.

In these sulpho-salts, as further explained on p. 248, sulphur takes the place of the oxygen in the commoner and better understood oxygen-acids (as carbonic acid, H_2CO_3, sulphuric acid, H_2SO_4, phosphoric acid, H_3PO_4, etc.).

The species included are salts of the sulpho-acids of trivalent *arsenic*, *antimony* and *bismuth*. The most important acids are the ortho-acids, H_3AsS_3, etc., and the meta-acids, $HAsS_2$, etc.; but $H_4As_2S_5$, etc., and a series of others are included. The metals present as bases are chiefly *copper*, *silver*, *lead*; also *zinc*, *mercury*, *iron*, rarely others (as Ni, Co) in small amount. In view of the hypothetical character of many of the acids whose salts are here represented, there is a certain advantage, for the sake of comparison, in writing the composition after the dualistic method, $RS.As_2S_3$, $2RS.As_2S_3$, etc.

As a large part of the fifty species here included are rare and hence to be mentioned but briefly, the classification can be only partially developed. The divisions under the first and more important section of sulpharsenites, etc., with the prominent species under each, are as follows:

A. Acidic Division. $RS : (As,Sb,Bi)_2S_3 = 1 : 2,\ 2 : 3,\ 3 : 4,\ 4 : 5.$

B. Meta- Division. $RS : (As,Sb,Bi)_2S_3 = 1 : 1.$

General formula: $RAs_2S_4, RSb_2S_4, RBi_2S_4$.

Zinkenite Group.

Zinkenite	$PbS.Sb_2S_3$	**Emplectite**	$Cu_2S.Bi_2S_3$
Sartorite	$PbS.As_2S_3$	**Chalcostibite**	$Cu_2S.Sb_2S_3$, etc.
Also			
Miargyrite	$Ag_2S.Sb_2S_3$	**Lorandite**	$Tl_2S.As_2S_3$

C. Intermediate Division. $RS : (As,Sb,Bi)_2S_3 = 5 : 4,\ 3 : 2,\ 2 : 1,\ 5 : 2.$

Here belong

Plagionite	$5PbS.4Sb_2S_3$.		
Schirmerite	$3(Ag_2,Pb)S.2Bi_2S_3$	**Klaprotholite**	$3Cu_2S.2Bi_2S_3$, etc.
Binnite	$3Cu_2S.2As_2S_3$	**Warrenite**	$3PbS.2Sb_2S_3$

Jamesonite Group.

Jamesonite	$2PbS.Sb_2S_3$	**Cosalite**	$2PbS.Bi_2S_3$, etc.
Dufrenoysite	$2PbS.As_2S_3$		
Also **Freieslebenite**	$5(Ag_2,Pb)S.2Sb_2S_3$	**Boulangerite**	$5PbS.2S_2S_3$

D. Ortho- Division. $RS : (As,Sb,Bi)_2S_3 = 3 : 1$.

General formula: $\overset{I}{R}_3AsS_3, \overset{I}{R}_3SbS_3$; $\overset{II}{R}_3As_2S_6, \overset{II}{R}_3Sb_2S_6$, etc.

Bournonite Group.

Bournonite	$3(Cu_2,Pb)S.Sb_2S_3$	**Wittichenite**	$3Cu_2S.Bi_2S_3$
Aikinite	$3(Pb,Cu_2)S.Bi_2S_3$	**Lillianite**	$3PbS.Bi_2S_3$, etc.

Pyrargyrite Group.

Pyrargyrite	$3Ag_2S.Sb_2S_3$	**Proustite**	$3Ag_2S.As_2S_3$

E. Basic Division. $RS : (As,Sb,Bi)_2S_3 = 4 : 1, 5 : 1, 6 : 1, 9 : 1, 12 : 1$.

Tetrahedrite Group.

Tetrahedrite	$4Cu_2S.Sb_2S_3$	**Tennantite**	$4Cu_2S.As_2S_3$

Jordanite Group.

Jordanite	$4PbS.As_2S_3$	**Meneghinite**	$4PbS.Sb_2S_3$
Also			
Geocronite	$5PbS.Sb_2S_3$	**Stephanite**	$5Ag_2S.Sb_2S_3$
Kilbrickenite	$6PbS.Sb_2S_3$	**Beegerite**	$6PbS.Bi_2S_3$

Polybasite Group.

Polybasite	$9Ag_2S.Sb_2S_3$	**Pearceite**	$9Ag_2S.As_2S_3$
Polyargyrite	$12Ag_2S.Sb_2S_3$		

A. Acidic Division.

Livingstonite. $HgS.2Sb_2S_3$. Resembles stibnite in form. Color lead-gray; streak red. H = 2. G. = 4·81. From Huitzuco, Mexico.

Chiviatite. $2PbS.3Bi_2S_3$. Foliated massive. Color lead-gray. From Chiviato, Peru.

Cuprobismutite. Probably $3Cu_2S.4Bi_2S_3$, in part argentiferous. Resembles bismuthinite. G. = 6·3–6·7. From Hall valley, Park Co., Colorado.

Rezbanyite. $4PbS.5Bi_2S_3$. Fine-granular, massive. Color lead-gray. G. = 6·1–6·4. From Rezbanya, Hungary.

B. Meta- Division. $RS.As_2S_3$, $RS.Sb_2S_3$, etc.

Zinkenite Group. Orthorhombic.

ZINKENITE. Bleiantimonglanz *Germ.* Zinckenite.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}5575 : 1 : 0{\cdot}6353$. Crystals seldom distinct; sometimes in nearly hexagonal forms through twinning. Lateral faces longitudinally striated. Also columnar, fibrous, massive.

Cleavage not distinct. Fracture slightly uneven. H. = 3–3·5. G. = 5·30–5·35. Luster metallic. Color and streak steel-gray. Opaque.

Comp.—$PbSb_2S_4$ or $PbS.Sb_2S_3$ = Sulphur 22·3, antimony 41·8, lead 35·9 = 100. Arsenic sometimes replaces part of the antimony.

Pyr., etc.—Decrepitates and fuses very easily; in the closed tube gives a faint sublimate of sulphur, and antimony trisulphide. In the open tube sulphurous fumes and a white sublimate of oxide of antimony; the arsenical variety gives also arsenical fumes. On charcoal is almost entirely volatilized, giving a coating which on the outer edge is white, and near the assay dark yellow; with soda in R.F. yields globules of lead. Soluble in hot hydrochloric acid with evolution of hydrogen sulphide and separation of lead chloride on cooling.

Obs.—Occurs at Wolfsberg in the Harz; Kinzigthal, Baden; Sevier County, Arkansas; San Juan Co., Colorado.

Andorite. $Ag_2S.2PbS.3Sb_2S_3$. In prismatic, orthorhombic crystals. Color dark gray to black. From Felsöbánya. *Webnerite* and *Sundtite* belong here.

Sartorite. Skleroklas *Germ.* $PbS.As_2S_3$. In slender, striated crystals. G. = 5·393. Color dark lead-gray. Occurs in the dolomite of the Binnenthal.

Emplectite. Kupferwismuthglanz *Germ.* $Cu_2S.Bi_2S_3$. In thin striated prisms. G. = 6·3–6·5. Color grayish white to tin-white. Occurs in quartz at Schwarzenberg and Annaberg, Saxony.

Chalcostibite. Wolfsbergite. Kupferantimonglanz *Germ.* $Cu_2S.Sb_2S_3$. In small aggregated prisms; also fine granular, massive. G. = 4·75–5·0. Color between lead-gray and iron-gray. From Wolfsberg in the Harz. *Guejarite* from Spain is the same species.

Galenobismutite. $PbS.Bi_2S_3$; also with Ag.Cu. Crystalline columnar to compact. Color lead-gray to tin-white. G. = 6·9. From Nordmark, Sweden; Poughkeepsie Gulch, Colorado (*alaskaite*, argentiferous); Falun, Sweden (seleniferous).

Berthierite. Probably $FeS.Sb_2S_3$. Fibrous massive, granular. G. = 4·0. Color dark steel-gray. From Chazelles and Martouret, Auvergne; Bräunsdorf, Saxony, etc.

Matildite. $Ag_2S.Bi_2S_3$. In slender, prismatic crystals. G. = 6·9 Color gray. From Morochoca, Peru; Lake City, Colorado. PLENARGYRITE, from Schapbach, Baden, has probably the same composition and may be identical.

Miargyrite. $Ag_2S.Sb_2S_3$. In complex monoclinic crystals, also massive. H. = 2–2·5. G. = 5·1–5 30. Luster metallic-adamantine. Color iron-black to steel-gray, in thin splinters deep blood-red. Streak cherry-red. From Bräunsdorf, Saxony; Felsöbánya; Přibram, Bohemia; Clausthal, etc.

Lorandite. A sulpharsenide of thallium, $TlAsS_2$. Monoclinic. Color cochineal-red. From Allchar, Macedonia.

C. Intermediate Division.

Plagionite. Perhaps $5PbS.4Sb_2S_3$. Crystals thick tabular, monoclinic; also massive, granular to compact. G. = 5·4. Color blackish lead-gray. From Wolfsberg, etc.

Schirmerite. $3(Ag_2,Pb)S.2Bi_2S_3$. Massive, granular. G. = 6·74. Color lead-gray. Treasury lode, Park Co., Colorado.

Klaprotholite. $3Cu_2S.Bi_2S_3$. In furrowed prismatic crystals. G. = 4·6. Color steel-gray. Wittichen, Baden.

Binnite. Perhaps $3Cu_2S.2As_2S_3$. Isometric-tetrahedral; also massive. G. = 4·477. Color dark steel-gray to iron-black. From the dolomite of the Binnenthal.

Warrenite. Domingite. $3PS.2Sb_2S_3$. In wool-like aggregates of acicular crystals. Color grayish black. Gunnison Co., Colorado.

Jamesonite Group. $2RS.As_2S_3$, $2RS.Sb_2S_3$, etc. Orthorhombic. Prismatic angle about 80°.

JAMESONITE.

Orthorhombic. Axes: $\breve{a} : \bar{b} = 0·915 : 1$. $mm''' = 78° 40'$. In acicular crystals; common in capillary forms; also fibrous massive, parallel or divergent; compact massive.

Cleavage: basal, perfect; *b*, *m* less so. Fracture uneven to conchoidal. Brittle. H. = 2–3. G. = 5·5–6·0. Luster metallic. Color steel-gray to dark lead-gray. Streak grayish black. Opaque.

Comp.—$Pb_2Sb_2S_5$ or $2PbS.Sb_2S_3$ = Sulphur 19·7, antimony 29·5, lead 50·8 = 100. Most varieties show a little iron (1 to 3 p. c.), and some contain also silver, copper, and zinc.

Pyr.—Same as for zinkenite, p. 307.

Obs.—Occurs principally in Cornwall; also in Siberia; Hungary; at Valentia d'Alcantara in Spain; at the antimony mines in Sevier Co., Arkansas. Named after Prof. Robert Jameson of Edinburgh (1774–1854).

The *feather ore* (Federerz *Germ.*) occurs at Wolfsberg, etc., in the Harz; Freiberg, Schemnitz; in Tuscany, near Bottino.

Dufrenoysite. $2PbS.As_2S_3$. In highly modified orthorhombic crystals; also massive. Cleavage: *c* perfect. H. = 3. G. = 5·55–5·57. Color blackish lead-gray. From the Binnenthal, Switzerland, in dolomite.

RATHITE. A sulpharsenite of lead resembling dufrenoysite. From the Binnenthal.

Cosalite. $2PbS.Bi_2S_3$. Usually massive, fibrous or radiated. G. = 6·39–6·75. Color lead- or steel-gray. Cosala, Province of Sinaloa, Mexico; Bjelke mine (*bjelkite*), Nordmark, Sweden; Colorado.

Kobellite. $2PbS.(Bi,Sb)_2S_3$. Fibrous radiated or granular massive. G. = 6·3. Color lead-gray to steel-gray. From Hvena, Sweden; Ouray, Colorado.

Brongniardite. $PbS.Ag_2S.Sb_2S_3$. In isometric octahedrons and massive. G. = 5·950. Color grayish black. From Mexico.

Semseyite. Near jamesonite, perhaps $7PbS.3Sb_2S_3$. In small tabular monoclinic crystals. G. = 5·95. Color gray. From Felsőbánya, Hungary.

Schapbachite. $PbS.Ag_2S.Bi_2S_3$. In acicular crystals and granular massive. G. = 6·43. Color lead-gray. From Schapbach, Baden.

FREIESLEBENITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c}$ = 0·5871 : 1 : 0·9277; β = 87° 46′. Habit prismatic. G. = 6·2–6·4. Luster metallic. Color and streak light steel-gray inclining to silver-white, also to blackish lead-gray.

Comp.—$(Pb,Ag_2)_5Sb_4S_{11}$ or $5(Pb,Ag_2)S.2Sb_2S_3$.

Obs.—From the Himmelsfürst mine, at Freiberg, Saxony; Kapnik, Hungary; Felsőbánya; Hiendelencina, Spain; also from the Augusta Mt., Gunnison Co., Colorado.

Diaphorite. Like freieslebenite in composition but orthorhombic in form. G. = 5·9. From Přibram, Bohemia.

BOULANGERITE.

Orthorhombic. In crystalline plumose masses; granular, compact. H. = 2·5–3. G. = 5·75–6·0. Luster metallic. Color bluish lead-gray; often covered with yellow spots from oxidation. Opaque.

Comp.—$Pb_5Sb_4S_{11}$ or $5PbS.2Sb_2S_3$ = Sulphur 18·9, antimony 25·7, lead 55·4 = 100.

Pyr.—Same as for zinkenite, p. 307.

Obs.—Molières, Depart. du Gard, France; at Nerchinsk; Wolfsberg in the Harz; Přibram, Bohemia; near Bottino, Tuscany; Echo District, Union county, Nevada.

Embrithite and *plumbostib* are from Nerchinsk; they correspond nearly to $10PbS.3Sb_2S_3$, but the material analyzed may not have been quite pure.

D. Ortho- Division. $3RS.As_2S_3$, $3RS.Sb_2S_3$, etc.

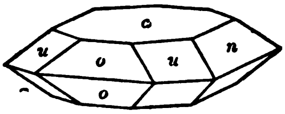
Bournonite Group. Orthorhombic. Prismatic angle 86° to 87°.

BOURNONITE. Rädelerz *Germ.* Wheel Ore.

Orthorhombic. Axes: $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}9380 : 1 : 0{\cdot}8969$.

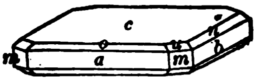
mm''',	$110 \wedge 1\bar{1}0 = 86°\ 20'$	*cn*,	$001 \wedge 011 = 41°\ 53'$
co,	$001 \wedge 101 = 43°\ 43'$	*cu*,	$001 \wedge 112 = 33°\ 15'$

624.



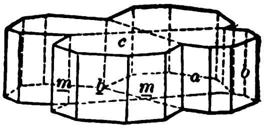
Harz.

625.



Nagyág.

626.



Kapnik.

Twins: tw. pl. *m*, often repeated, forming cruciform and wheel-shaped crystals. Also massive; granular, compact.

Cleavage: *b* imperfect; *a*, *c* less distinct. Fracture subconchoidal to uneven. Rather brittle. H. = 2·5–3. G. = 5·7–5·9. Luster metallic, brilliant. Color and streak steel-gray, inclining to blackish lead-gray or iron-black. Opaque.

Comp.—$(Pb,Cu_2)_3Sb_2S_6$ or $3(Pb,Cu_2)S.Sb_2S_3 = PbCuSbS_3$ (if $Pb : Cu_2 = 2 : 1$) = Sulphur 19·8, antimony 24·7, lead 42·5, copper 13·0 = 100.

Pyr., etc.—In the closed tube decrepitates, and gives a dark red sublimate. In the open tube gives sulphur dioxide, and a white sublimate of oxide of antimony. B.B. on charcoal fuses easily, and at first coats the coal white; continued blowing gives a yellow coating of lead oxide; the residue, treated with soda in R.F., gives a globule of copper. Decomposed by nitric acid, affording a blue solution, and leaving a residue of sulphur, and a white powder containing antimony and lead.

Obs.—From Neudorf in the Harz; also Wolfsberg, Clausthal, and Andreasberg; Přibram, Bohemia; Kapnik, Hungary; Endellion at Wheal Boys, Cornwall; in Mexico; Huasco-Alto, Chili.

In the U. S., at the Boggs mine, Yavapai Co., Arizona; also Montgomery Co., Arkansas; reported from San Juan Co., Colorado. In Canada, in the township of Marmora, Hastings Co., and Darling, Lanark Co., Ontario.

Aikinite. $3(Pb,Cu_2)S.Bi_2S_3$. Acicular crystals; also massive. G. = 6·1–6·8. Color blackish lead-gray. From Berezov near Ekaterinburg, Urals.

Wittichenite. $3Cu_2S.Bi_2S_3$. Rarely in crystals resembling bournonite; also massive. G. = 4·5. Color steel-gray or tin-white. Wittichen, Baden, etc.

Stylotypite. $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$. In orthorhombic crystals, in cruciform twins like bournonite. G. = 4·79. Color iron-black. Copiapo, Chili.

Lillianite. $3PbS.BiSbS_3$ and $3PbS.Bi_2S_3$. Massive, crystalline. Color steel-gray. Hvena, Sweden; Leadville, Colorado (argentiferous).

Guitermanite. Perhaps $3PbS.As_2S_3$. Massive, compact. G. = 5·94. Color bluish gray. Zuñi mine, Silverton, Colorado.

Tapalpite. A sulpho-telluride of bismuth and silver, perhaps $3Ag_2(S,Te).Bi_2(S,Te)_3$. Massive, granular. G. = 7·80. Sierra de Tapalpa, Jalisco, Mexico.

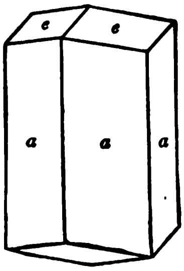
Pyrargyrite Group. Rhombohedral-hemimorphic.

PYRARGYRITE. Ruby Silver Ore. Dark Red Silver Ore. Dunkles Rothgültigerz, Antimonsilberblende *Germ.*

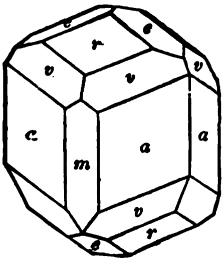
Rhombohedral-hemimorphic. Axis: $\dot{c} = 0{\cdot}7892$; $0001 \wedge 10\bar{1}1 = 42° 20\frac{1}{2}'$.

ee', $01\bar{1}2 \wedge \bar{1}012 = 42° \ 5'$ *vv'*, $21\bar{3}1 \wedge \bar{2}3\bar{1}1 = 74° 25'$
rr', $10\bar{1}1 \wedge \bar{1}101 = 71° 22'$ *vv*ᵛ, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35° 12'$

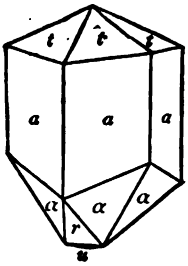
627.



628.



629.



Crystals commonly prismatic. Twins: tw. pl. *a*, very common, the axes $\dot{c}$ parallel; *u* ($10\bar{1}4$), also common. Also massive, compact.

Cleavage: *r* distinct; *e* imperfect. Fracture conchoidal to uneven. Brittle. H. = 2·5. G. = 5·77–5·86; 5·85 if pure. Luster metallic-adamantine. Color black to grayish black, by transmitted light deep red. Streak purplish red. Nearly opaque, but transparent in very thin splinters. Optically —. Refractive indices, $\omega = 3{\cdot}084$, $\epsilon = 2{\cdot}881$ Fizeau.

Comp.—Ag_3SbS_3 or $3Ag_2S.Sb_2S_3$ = Sulphur 17·8, antimony 22·3, silver 59·9 = 100. Some varieties contain small amounts of arsenic.

Pyr., etc.—In the closed tube fuses and gives a reddish sublimate of antimony oxysulphide; in the open tube sulphurous fumes and a white sublimate of oxide of antimony. B.B. on charcoal fuses with spirting to a globule, coats the coal white, and the assay is converted into silver sulphide, which, treated in O.F., or with soda in R.F., gives a globule of silver. In case arsenic is present it may be detected by fusing the pulverized mineral with soda on charcoal in R.F. Decomposed by nitric acid with the separation of sulphur and of antimony trioxide.

Obs.—Occurs at Andreasberg in the Harz; Freiberg, Saxony; Přibram, Bohemia; Schemnitz, etc., Hungary; Kongsberg, Norway; Gaudalcanal, Spain; in Cornwall. In Mexico it is worked at Guanajuato and elsewhere as an ore of silver. In Chili with proustite at Chañarcillo near Copiapo.

In Colorado, not uncommon; thus in Ruby district, Gunnison Co.; with sphalerite in Sneffle's distr., Ouray Co., etc. In Nevada, at Washoe in Daney Mine; about Austin, Reese river; at Poorman lode, Idaho, in masses with cerargyrite. In New Mexico, Utah, and Arizona with silver ores at various points.

Named from πῦρ, *fire*, and ἄργυρος, *silver*, in allusion to the color.

PROUSTITE. Ruby Silver Ore. Light Red Silver Ore. Lichtes Rothgültigerz. Arsensilberblende *Germ.*

Rhombohedral-hemimorphic. Axis $\dot{c} = 0{\cdot}8039$; $0001 \wedge 10\bar{1}1 = 42° 52'$.

ee', $01\bar{1}2 \wedge \bar{1}012 = 42° 46'$ *vv'*, $21\bar{3}1 \wedge 23\bar{1}1 = 74° 39'$
rr', $10\bar{1}1 \wedge \bar{1}101 = 72° 12'$ *vv*ᵛ, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35° 18'$

Crystals often acute rhombohedral or scalenohedral. Twins: tw. pl. *u* ($10\bar{1}4$) and *r*. Also massive, compact.

Cleavage: *r* distinct. Fracture conchoidal to uneven. Brittle. H. = 2–2·5. G. = 5·57–5·64; 5·57 if pure. Luster adamantine. Color scarlet-vermilion; streak same, also inclined to aurora-red. Transparent to translucent. Optically negative. Double refraction strong. $\omega_r = 2·979$.

Comp.—Ag_3AsS_3 or $3Ag_2S.As_2S_3$ = Sulphur 19·4, arsenic 15·2, silver 65·4 = 100.

Pyr., etc.—In the closed tube fuses easily, and gives a faint sublimate of arsenic trisulphide; in the open tube sulphurous fumes and a white crystalline sublimate of arsenic trioxide. B.B. on charcoal fuses and emits odors of sulphur and arsenic; with soda in R.F. gives a globule of silver. Decomposed by nitric acid, with separation of sulphur.

Obs.—Occurs at Freiberg, Johanngeorgenstadt, etc., in Saxony; Joachimsthal, Bohemia; Chalanches in Dauphiné; Guadalcanal in Spain; in Mexico; Peru; Chili, at Chañarcillo in magnificent crystallizations.

In Colorado, Ruby distr., Gunnison Co.; Sheridan mine, San Miguel Co.; Yankee Girl mine, Ouray Co. In Arizona, with silver ores at various points. In Nevada, in the Daney mine, and in Comstock lode, rare; Idaho, at the Poorman lode.

Named after the French chemist, J. L. Proust (1755–1826).

Sanguinite. Near proustite in composition. In glittering scales, hexagonal or rhombohedral. From Chañarcillo, Chili.

Falkenhaynite. Perhaps $3Cu_2S.Sb_2S_3$. Massive, resembling galena. From Joachimsthal, Bohemia.

Pyrostilpnite. Like pyrargyrite, $3Ag_2S.Sb_2S_3$. In tufts of slender (monoclinic) crystals. G. = 4·25. Color hyacinth-red. From Andreasberg in the Harz; Freiberg; Přibram.

Rittingerite. Contains arsenic, selenium, and silver. In small tabular crystals. G. = 5·63. Color blackish brown to iron-black; hyacinth-red by transmitted light. Streak orange-yellow. From Chañarcillo, Chili.

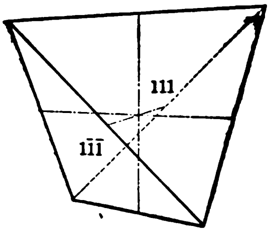
E. Basic Division.

Tetrahedrite Group. Isometric-tetrahedral.

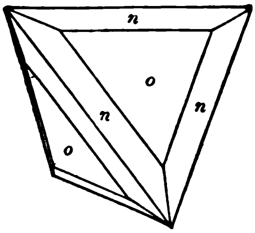
TETRAHEDRITE. Gray Copper Ore. Fahlerz *Germ.*

Isometric-tetrahedral. Habit tetrahedral. Twins: tw. pl. *o*; also with parallel axes (Fig. 354, p. 121, Fig. 370, p. 124). Also massive; granular, coarse or fine; compact.

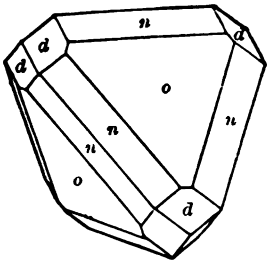
630.



631.



632.



Cleavage none. Fracture subconchoidal to uneven. Rather brittle. H. = 3–4. G. = 4·4–5·1. Luster metallic, often splendent. Color between flint-gray and iron-black. Streak like color, sometimes inclining to brown and cherry-red. Opaque; sometimes subtranslucent (cherry-red) in very thin splinters.

Comp., Var.—Essentially $Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$ = Sulphur 23·1, antimony 24·8, copper 52·1 = 100.

Antimony and arsenic are usually both present and thus tetrahedrite graduates into the allied species tennantite. There are also varieties containing bismuth, chiefly at the arsenical end of the series. Further the copper may be replaced by iron, zinc, silver, mercury, lead, and rarely cobalt and nickel.

Var.—*Ordinary.* Contains little or no silver. Color steel-gray to dark gray and iron-black. G. = 4·75–4·9.

Argentiferous; Freibergite, Weissgiltigerz *Germ.* Contains 3 to 30 p. c. of silver. Color usually steel-gray, lighter than the ordinary varieties; sometimes iron-black; streak often reddish. G. = 4·85–5·0.

Mercurial; Schwatzite. Contains 6 to 17 p. c. of mercury. Color dark gray to iron-black. Luster often dull. G. = 5·10 chiefly.

Malinowskite, from Peru and a similar variety from Arizona, contain 13–16 p. c. of lead.

Pyr., etc.—Differ in the different varieties. In the closed tube all the antimonial kinds fuse and give a dark red sublimate of antimony oxysulphide; if much arsenic is present, a sublimate of arsenic trisulphide first forms. In the open tube fuses, gives sulphurous fumes and a white sublimate of antimony oxide; if arsenic is present, a crystalline volatile sublimate condenses with the antimony; if the ore contains mercury it condenses in minute metallic globules. B.B. on charcoal fuses, gives a coating of the oxides of antimony and sometimes arsenic, zinc, and lead; arsenic is detected by the odor when the coating is treated in R.F. The roasted mineral gives with the fluxes reactions for iron and copper; with soda yields a globule of metallic copper. Decomposed by nitric acid, with separation of sulphur and antimony trioxide.

Diff.—Distinguished by its form, when crystallized, by its deep black color on fracture and brilliant metallic luster. It is harder than bournonite and much softer than magnetite; the blowpipe characters are usually distinctive.

Obs.—Often associated with chalcopyrite, pyrite, sphalerite, galena, and various other silver, lead, and copper ores; also siderite. Occurs at many Cornish mines; thus at the Herodsfoot mine, Liskeard, in tetrahedral crystals often coated with iridescent chalcopyrite; the Levant mine near St. Just. From Andreasberg and Clausthal in the Harz; Freiberg, Saxony; Dillenburg and Horhausen in Nassau; at Müsen; various mines in the Black Forest; Přibram, Bohemia; Kogel near Brixlegg in Tyrol; Kapnik, Herrengrund, Hungary. In Mexico, at Durango, Guanajuato; Chili; Bolivia, etc. The *argentiferous* variety occurs especially at Freiberg; Přibram; Huallanca in Peru, and elsewhere. The *mercurial* variety at Schmölnitz, Hungary; Schwatz, Tyrol; valleys of Angina and Castello, Tuscany.

In the U. S., tetrahedrite occurs at the Kellogg mines, Arkansas. In Colorado, in Clear Creek and Summit Cos.; the Ulay mine, Lake Co.; with pyrargyrite in Ruby district, Gunnison Co., etc. Much of the Colorado "gray copper" is tennantite (see below). In Nevada, abundant in Humboldt Co.; near Austin in Lander Co.; Isabella mine, Reese river. In Arizona at the Heintzelman mine; at various points in British Columbia.

TENNANTITE.

Isometric-tetrahedral. Crystals often dodecahedral. Also massive, compact. H. = 3–4. G. = 4·37–4·49. Color blackish lead-gray to iron-black.

Comp.—Essentially $Cu_8As_2S_7$ or $4Cu_2S.As_2S_3$ = Sulphur 25·5, arsenic 17·0, copper 57·5 = 100.

Var.—Often contains antimony and thus graduates into tetrahedrite. The original tennantite from Cornwall contains only copper and iron. In crystals, habit dodecahedral.

Sandbergerite, Kupferblende Germ., contains 7 p. c. of zinc. *Fredricite* from Sweden has, besides copper, also iron, lead, silver, and tin.

Found at the Cornish mines, particularly at Wheal Jewel in Gwennap, and Wheal Unity in Gwinear; at Freiberg (*Kupferblende*); at the Wilhelmine mine in the Spessart; Skutterud, Norway. Near Central City and elsewhere in Colorado. At Capelton, Pr. Quebec, Canada. Named after the chemist, Smithson Tennant (1761–1815). See further above.

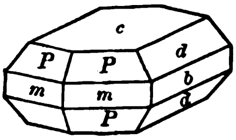
Jordanite. $4PbS.As_2S_3$. Monoclinic; often pseudohexagonal by twinning. G. = 6·39. Color lead-gray. From the Binnenthal; Nagyág, Transylvania.

Meneghinite. $4PbS.Sb_2S_3$. Orthorhombic. In slender prismatic crystals; also massive. G. = 6·34–6·43. Color blackish lead-gray. From Bottino, Tuscany; Marble Lake, Barrie ownship, Ontario.

STEPHANITE. Melanglanz *Germ.* Brittle Silver Ore.

Orthorhombic. Axes $\breve{a} : \bar{b} : \grave{c} = 0{\cdot}6292 : 1 : 0{\cdot}6851$.

633.



mm''', 110 ∧ 1$\bar{1}$0 = 64° 21′
cβ, 001 ∧ 101 = 47° 26′
ck, 001 ∧ 011 = 34° 25′
cd, 001 ∧ 021 = 53° 52′
ch, 001 ∧ 112 = 32° 45′
cP, 001 ∧ 111 = 52° 9′

Crystals usually short prismatic or tabular ∥ $\grave{c}$. Twins: tw. pl. *m*, often repeated, pseudo-hexagonal. Also massive, compact and disseminated.

Cleavage: *b*, *d* imperfect. Fracture subconchoidal to uneven. Brittle. H. = 2–2·5. G. = 6·2–6·3. Luster metallic. Color and streak iron-black. Opaque.

Comp.—Ag_5SbS_4 or $5Ag_2S.Sb_2S_3$ = Sulphur 16·3, antimony 15·2, silver 68·5 = 100.

Pyr.—In the closed tube decrepitates, fuses, and after long heating gives a faint sublimate of antimony oxysulphide. In the open tube fuses, giving off antimonial and sulphurous fumes. B.B. on charcoal fuses with projection of small particles, coats the coal with oxide of antimony, which after long blowing is colored red from oxidized silver, and a globule of metallic silver is obtained. Soluble in dilute heated nitric acid, sulphur and antimony trioxide being deposited.

Obs.—In veins, with other silver ores, at Freiberg, Schneeberg, etc., in Saxony; Přibram, Bohemia; Schemnitz, Hungary; Andreasberg in the Harz; Kongsberg, Norway; Wheal Newton, Cornwall; Mexico; Peru; Chañarcillo, Chili.

In Nevada, in the Comstock lode, Reese river, etc. In Idaho, at the silver mines at Yankee Fork, Queen's River district.

Named after the Archduke Stéphan, Mining Director of Austria.

Geocronite. $5PbS.Sb_2S_3$. Rarely in orthorhombic crystals; usually massive, granular. G. = 6·4. Color lead-gray. From Sala, Sweden, etc.

Beegerite. $6PbS.Bi_2S_3$. Massive, indistinctly crystallized. G. = 7·27. Color light to dark gray. From Park Co., Colorado.

Kilbrickenite. Perhaps $6PbS.Sb_2S_3$. Massive. G. = 6·41. Color lead-gray. From Kilbricken, Co. Clare, Ireland.

Polybasite Group. $9RS_2.As_2S_3$, $9RS.Sb_2S_3$. Monoclinic, pseudo-rhombohedral.

POLYBASITE. Sprödglaserz, Eugenglanz *Germ.*

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 1{\cdot}7309 : 1 : 1{\cdot}5796$, $\beta = 90° 0'$. Prismatic angle 60° 2′. In short six-sided tabular prisms, with beveled edges; *c* faces with triangular striations; in part repeated twins, tw. pl. *m*.

Cleavage: *c* imperfect. Fracture uneven. H. = 2–3. G. = 6·0–6·2. Luster metallic. Color iron-black, in thin splinters cherry-red. Streak black. Nearly opaque.

Comp.—Ag_9SbS_6 or $9Ag_2S.Sb_2S_3$ = Sulphur 15·0, antimony 9·4, silver 75·6 = 100. Part of the silver is replaced by copper; also the arsenic by antimony.

Pyr., etc.—In the open tube fuses, gives sulphurous and antimonial fumes, the latter forming a white sublimate, sometimes mixed with crystalline arsenic trioxide. B.B. fuses with spirting to a globule, gives off sulphur (sometimes arsenic), and coats the coal with antimony trioxide; with long-continued blowing some varieties give a faint yellowish-white coating of zinc oxide, and a metallic globule, which with salt of phosphorus reacts for copper, and cupelled with lead gives pure silver. Decomposed by nitric acid.

Obs.—Occurs in the mines of Guanajuato, Mexico; at Tres Puntos, desert of Atacama; at Freiberg and Přibram. In Nevada, at the Reese mines and at the Comstock Lode. In Colorado, at the Terrible Lode, Clear Creek Co. In Arizona, at the Silver King mine.

Named from *πολύς, many,* and *βάσις, base,* in allusion to the basic character of the compound.

Pearceite. $9Ag_2S.As_2S_5$. Monoclinic, pseudo-rhombohedral. From Aspen, Colorado; Marysville, Lewis and Clarke Co., Montana.

Polyargyrite. $12Ag_2S.Sb_2S_3$. In indistinct isometric crystals. G. = 6·97. Color iron-black. Wolfach, Baden.

II. Sulpharsenates, Sulphantimonates; Sulpho-stannates, etc.

Here are included a few minerals, chiefly sulpho-salts of quantivalent arsenic and antimony; also several sulpho-stannates and rare sulpho-germanates.

ENARGITE.

Orthorhombic. Axes: $\breve{a} : \bar{b} : \acute{c} = 0{\cdot}8711 : 1 : 0{\cdot}8248$.

Crystals usually small; prismatic faces vertically striated. Twins: tw. pl. *x* (320) in star-shaped trillings. Also massive, granular, or columnar.

Cleavage: *m* perfect; *a*, *b* distinct; *c* indistinct. Fracture uneven. Brittle. H. = 3. G. = 4·43–4·45. Luster metallic. Color grayish black to iron-black. Streak grayish black. Opaque.

Comp.—Cu_3AsS_4 or $3Cu_2S.As_2S_5$ = Sulphur 32·6, arsenic 19·1, copper 48·3 = 100. Antimony is often present, cf. famatinite.

Pyr.—In the closed tube decrepitates, and gives a sublimate of sulphur; at a higher temperature fuses, and gives a sublimate of sulphide of arsenic. In the open tube, heated gently, the powdered mineral gives off sulphurous and arsenical fumes, the latter condensing to a sublimate containing some antimony oxide. B.B. on charcoal fuses, and gives a faint coating of the oxides of arsenic, antimony, and zinc; the roasted mineral with the fluxes gives a globule of metallic copper. Soluble in aqua regia.

Obs.—From Morococha, Cordilleras of Peru; in Chili and Argentina; Mexico; Matzenköpfl, Brixlegg, Tyrol; Mancayan, island of Luzon.

In the U. S., at Brewster's gold mine, Chesterfield dist., S. Carolina; in Colorado, at mines near Central City, Gilpin Co.; in Park Co., at the Missouri mine, etc. In southern Utah; also in the Tintic district; near Butte, Montana.

CLARITE. Perhaps identical with enargite. From the Clara mine, Schapbach, Baden.

LUZONITE. Composition of enargite, but supposed to differ in crystallization. Massive. G. = 4·42. Color steel-gray. From the island of Luzon.

Famatinite. $3Cu_2S.Sb_2S_5$, isomorphous with enargite. G. = 4·57. Color gray with tinge of copper-red. From the Sierra de Famatina, Argentina.

Xanthoconite.—$3Ag_2S.As_2S_5$. In thin tabular rhombohedral crystals; also massive, reniform. G. = 5. Color orange-yellow. From Freiberg.

Epiboulangerite.—$3PbS.Sb_2S_3$. In striated prismatic needles and granular. G. = 6·31. Color dark bluish gray to black. From Altenberg.

Epigenite.—Perhaps $4Cu_2S.3FeS.As_2S_5$. In short prisms resembling arsenopyrite. Color steel-gray. From Wittichen, Baden.

STANNITE. Tin Pyrites. Bell-metal Ore. Zinnkies *Germ.*

Isometric-tetrahedral. Massive, granular, and disseminated.

Cleavage: cubic, indistinct. Fracture uneven. Brittle. H. = 4. G. = 4·3–4·522; 4·506 Zinnwald. Luster metallic. Streak blackish. Color steel-gray to iron-black, the former when pure; sometimes a bluish tarnish; often yellowish from the presence of chalcopyrite. Opaque.

Comp.—A sulpho-stannate of copper, iron and sometimes zinc, Cu_2FeSnS_4 or $Cu_2S.FeS.SnS_2$ = Sulphur 29·9, tin 27·5, copper 29·5, iron 13·1 = 100.

Pyr., etc.—In the closed tube decrepitates, and gives a faint sublimate; in the open tube sulphurous fumes. B.B. on charcoal fuses to a globule, which in O F. gives off sulphur, and coats the coal with tin dioxide; the roasted mineral treated with borax gives reactions for iron and copper. Decomposed by nitric acid, affording a blue solution, with separation of sulphur and tin dioxide.

Obs.—Formerly found at Wheal Rock, Cornwall; and at Carn Brea; more recently in granite at St. Michael's Mount; also at Stenna Gwynn, etc.; at the Cronebane mine, Co. Wicklow, in Ireland; Zinnwald, in the Erzgebirge. From the Black Hills, So. Dakota.

Argyrodite. A silver sulpho-germanate, Ag_8GeS_6 or $4Ag_2S.GeS_2$. Isometric, crystals usually indistinct; also massive, compact. H. = 2·5. G. = 6·085–6·111. Luster metallic. Color steel-gray on a fresh fracture, with a tinge of red turning to violet. From the Himmelsfürst mine, Freiberg, Saxony.

Canfieldite. Ag_8SnS_6 or $4Ag_2S.SnS_2$, the tin in part replaced by germanium. Isometric, perhaps tetrahedral; in octahedrons with *d* (110). G. = 6·28. Luster metallic. Color black. La Paz, Bolivia.

Franckeite. Perhaps $Pb_5Sb_2Sn_2S_{12}$, Groth. **Massive.** G. = 5·55. Color blackish gray to black. Bolivia.

Cylindrite. Kylindrite. Perhaps $Pb_6Sb_2Sn_6S_{21}$, Groth. H. = 2·5–3. G. = 5·42. Luster metallic. Color blackish lead-gray. Poopó, Bolivia.

IV. HALOIDS.—CHLORIDES, BROMIDES, IODIDES; FLUORIDES.

I. Anhydrous Chlorides, Bromides, Iodides; Fluorides.
II. Oxychlorides; Oxyfluorides.
III. Hydrous Chlorides; Hydrous Fluorides.

The Fourth Class includes the haloids, that is, the compounds with the halogen elements, chlorine, bromine, iodine, and also the less closely related fluorine.

I. Anhydrous Chlorides, Bromides, Iodides; Fluorides.

CALOMEL. Horn Quicksilver. Chlorquecksilber, Quecksilberhornerz *Germ.*

Tetragonal. Axis $\acute{c} = 1·7229$; 001 ∧ 101 = 59° 52′. Crystals sometimes tabular ‖ *c*; also pyramidal; often highly complex.

Cleavage: *a* rather distinct; also *r*(111). Fracture conchoidal. Sectile. H. = 1–2. G. = 6·482 Haid. Luster adamantine. Color white, yellowish gray, or ash-gray, also grayish, and yellowish white, brown. Streak pale yellowish white. Translucent—subtranslucent. Optically +.

Comp.—Mercurous chloride, Hg_2Cl_2 = Chlorine 15·1, mercury 84·9 = 100.

Pyr., **etc.**—In the closed tube volatilizes without fusion, condensing in the cold part of the tube as a white sublimate; with soda gives a sublimate of metallic mercury. B.B. on charcoal volatilizes, coating the coal white. Insoluble in water, but dissolved by aqua regia; blackens when treated with alkalies.

Obs.—Usually associated with cinnabar. Thus at Moschellandsberg in the Palatinate; at Idria in Carniola; Almaden in Spain; at Mt. Avala near Belgrade in Servia.

Calomel is an old term of uncertain origin and meaning, perhaps from καλός, *beautiful*, and μέλι, *honey*, the taste being sweet, and the compound the *Mercurius dulcis* of early chemistry; or from καλός and μέλας, *black*.

Nantokite. Cuprous chloride, Cu_2Cl_2. Granular, massive. Cleavage cubic. H. = 2–2·5. G. = 3·93. Luster adamantine. Colorless to white or grayish. From Nantoko, Chili; New South Wales.

Marshite. Cuprous iodide, Cu_2I_2. Isometric-tetrahedral. Color oil-brown. Broken Hill mines, New South Wales.

Halite Group. $\overset{\mathrm{I}}{R}Cl$, $\overset{\mathrm{I}}{R}Br$, $\overset{\mathrm{I}}{R}I$. Isometric.

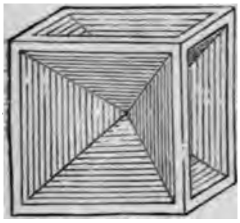
Halite	$NaCl$	**Embolite**	$Ag(Cl,Br)$
Sylvite	KCl	**Bromyrite**	$AgBr$
Sal Ammoniac	$(NH_4)Cl$	**Iodobromite**	$Ag(Cl,Br,I)$
Cerargyrite	$AgCl$	**Miersite**	AgI

The HALITE GROUP includes the halogen compounds of the closely related metals, sodium, potassium, and silver, also ammonium (NH_4). They crystallize in the isometric system, the cubic form being the most common. Sylvite and sal-ammoniac are plagihedral, and the same may be true of the others.

HALITE. COMMON or ROCK SALT. Steinsalz, Bergsalz *Germ.*

Isometric. Usually in cubes; crystals sometimes distorted, or with cavernous faces. Also massive, granular to compact; less often columnar.

634.



Cleavage: cubic, perfect. Fracture conchoidal. Rather brittle. H. = 2·5. G. = 2·1–2·6; pure crystals 2·135. Luster vitreous. Colorless or white, also yellowish, reddish, bluish, purplish. Transparent to translucent. Soluble; taste saline. Refractive index 1·5442 Na. Highly diathermanous.

Comp.—Sodium chloride, $NaCl$ = Chlorine 39·4, sodium 60·6 = 100. Commonly mixed with calcium sulphate, calcium chloride, magnesium chloride, and sometimes magnesium sulphate, which render it liable to deliquesce.

Pyr., etc.—In the closed tube fuses, often with decrepitation; when fused on the platinum wire colors the flame deep yellow. Added to a salt of phosphorus bead which has been saturated with oxide of copper, it colors the flame a deep azure-blue. Dissolves readily in three parts of water.

Diff.—Distinguished by its solubility (taste), softness, perfect cubic cleavage.

Obs.—Common salt occurs in extensive but irregular beds in rocks of various ages, associated with gypsum, polyhalite, anhydrite, carnallite, clay, sandstone, and calcite; also in solution forming salt springs; similarly in the water of the ocean and salt seas.

The principal salt mines of Europe are at Stassfurt, near Magdeburg; Wieliczka, in Poland; at Hall, in Tyrol; and along the range through Reichenthal in Bavaria, Hallein in Salzburg, Hallstatt, Ischl, and Ebensee, in Upper Austria, and Aussee in Styria; in Hungary, at Marmoros and elsewhere; Transylvania; Wallachia, Galicia, and Upper Silesia; Vic and Dieuze in France; Valley of Cardona and elsewhere in Spain; Bex in Switzerland; and Northwich in Cheshire, England. At the Austrian mines, where it contains much clay, the salt is dissolved in large chambers, and the clay thus precipitated. After a time the water, saturated with the salt, is conveyed by aqueducts to evaporating houses, and the chambers, after being cleared out, are again filled.

Salt also occurs, forming hills and covering extended plains, near Lake Urumia, the Caspian Sea, etc. In Algeria; in Abyssinia. In India in enormous deposits in the Salt Range of the Punjab. In China and Asiatic Russia; in South America, in Peru, and at Zipaquera and Nemocon, the former a large mine long explored in the Cordilleras of U. S. of Colombia; clear salt is obtained from the Cerro de Sal, San Domingo.

In the United States, salt has been found in large amount in central and western New York. Salt wells had long been worked in this region, but rock salt is now known to exist over a large area from Ithaca at the head of Cayuga Lake, Tompkins Co., and Canandaigua Lake, Ontario Co., through Livingston Co., also Genesee, Wyoming, and Erie Cos. The salt is found in beds with an average thickness of 75 feet, but sometimes much thicker, and at varying depths from 1000 to 2000 feet and more; the depth increases southward with the dip of the strata. The rocks belong to the Salina period of the Upper Silurian. Salt has also been found near Cleveland, Ohio, associated with gypsum; in Washington Co., West Virginia, in the Holston and Kanawha valleys; in Kansas; at Petite Anse, Louisiana; along the Rio Virgin in Lincoln Co., Nevada, in extensive beds of great purity; in Utah, near Nephi, Juab Co., and Salina, Sevier Co.; in Arizona, on the Rio Verde, with thenardite, etc.; in California, San Diego Co.

Brine springs are very numerous in the Middle and Western States. Vast lakes of salt water exist in many parts of the world. The Great Salt Lake in Utah is 2,000 square miles in area; L. Gale found in this water 20·196 per cent. of sodium chloride. The Dead and Caspian seas are salt, and the waters of the former contain 20 to 26 parts of solid matter in 100 parts. Sodium chloride is the prominent salt present in the ocean.

Huantajayite. $20NaCl + AgCl$. In cubic crystals and as an incrustation. H. = 2, not sectile. Color white. From Huantajaya, Tarapaca, Chili.

SYLVITE.

Isometric-plagihedral. Also in granular crystalline masses; compact. Cleavage: cubic, perfect. Fracture uneven. Brittle. H. = 2. G. = 1·97–

1·99. Luster vitreous. Colorless, white, bluish or yellowish red from inclusions. Soluble; taste resembling that of common salt, but bitter.

Comp.—Potassium chloride, KCl = Chlorine 47·6, potassium 52·4 = 100. Sometimes contains sodium chloride.

Pyr., **etc.**—B.B. in the platinum loop fuses, and gives a violet color to the outer flame. Dissolves completely in water. Heated with sulphuric acid gives off hydrochloric acid gas.

Obs.—Occurs at Vesuvius, about the fumaroles of the volcano. Also at Stassfurt; at Leopoldshall (*leopoldite*); at Kalusz in Galicia.

Sal Ammoniac. Ammonium chloride, NH_4Cl. Observed as a white incrustation about volcanoes, as at Etna, Vesuvius, etc.

CERARGYRITE. Silberhornerz, Hornsilber *Germ.* Horn Silver.

Isometric. Habit cubic. Twins: tw. pl. *o*. Usually massive and resembling wax; sometimes columnar; often in crusts.

Cleavage none. Fracture somewhat conchoidal. Highly sectile. H. = 1–1·5. G. = 5·552. Luster resinous to adamantine. Color pearl-gray, grayish green, whitish to colorless, rarely violet-blue; on exposure to the light turns violet-brown. Transparent to translucent. Index, n_y = 2·0611 Na.

Comp.—Silver chloride = Chlorine 24·7, silver 75·3 = 100. Some varieties contain mercury.

Pyr., **etc.**—In the closed tube fuses without decomposition. B.B. on charcoal gives a globule of metallic silver. Added to a bead of salt of phosphorus, previously saturated with oxide of copper and heated in O.F., imparts an intense azure-blue to the flame. Insoluble in nitric acid, but soluble in ammonia.

Obs.—Occurs in veins of clay slate, accompanying other ores of silver, and usually only in the higher parts of these veins. It has also been observed with ocherous varieties of brown iron ore; also with several copper ores, calcite, barite, etc.; upon stibiconite.

The largest masses are brought from Peru, Chili, and Mexico, where it occurs with native silver. Also once obtained from Johanngeorgenstadt and Freiberg; Andreasberg (earthy var., *Buttermilcherz*); occurs in the Altai; at Kongsberg in Norway; in Alsace.

In the U. S., in Colorado, near Leadville, Lake Co.; near Breckenridge Summit Co., and elsewhere. In Nevada near Austin, Lander Co.; at mines of Comstock lode. In Idaho, at the Poorman mine, in crystals; also at various other mines. In Utah, in Beaver, Summit and Salt Lake counties.

Named from *κέρας*, *horn*, and *ἄργυρος*, *silver*.

Embolite. Silver chloro-bromide. $Ag(Br.Cl)$, the ratio of chlorine to bromine varying widely. Usually massive. Resembles cerargyrite, but color grayish green to yellowish green and yellow. Abundant in Chili, less so elsewhere.

Bromyrite. Silver bromide, $AgBr$. G. = 5·8–6. Color bright yellow to amber-yellow; slightly greenish. From Mexico; Chili; Huelgoet in Brittany.

Iodobromite. $2AgCl.2AgBr.AgI$. Isometric; *o* with *a*. G. = 5·713. Color sulphur-yellow, greenish. From near Dernbach, Nassau.

Miersite. Silver iodide, AgI, crystallizing in the isometric system; probably tetrahedral like marshite (p. 317). In bright yellow crystals from the Broken Hill Silver Mines, New South Wales.

Cuproiodargyrite. A copper-silver iodide, occurring as a sulphur-yellow incrustation at Huantajaya, Peru.

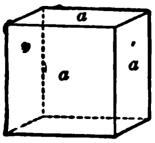
Iodyrite. Silver iodide, AgI. Hexagonal-hemimorphic (Fig. 211, p. 71); usually in thin plates; pale yellow or green. G. = 5·6–5·7. From Mexico, Chili, etc. Lake Valley, Sierra Co., New Mexico.

Fluorite Group. $\overset{\text{II}}{R}F_2, \overset{\text{II}}{R}Cl_2$.

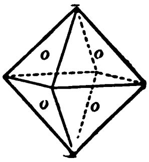
The species here included are Fluorite, CaF_2, and the rare Hydrophilite, $CaCl_2$. Both are isometric, habit cubic.

FLUORITE or FLUOR SPAR. Flussspath *Germ.*

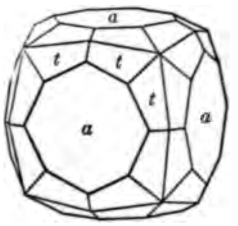
635.



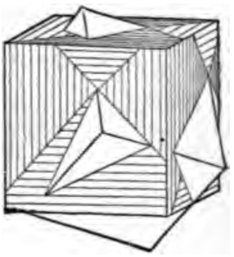
636.



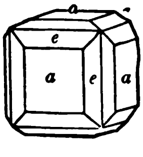
639.



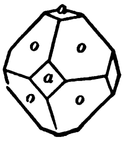
640.



637.



638



Isometric. Habit cubic; less frequently octahedral or dodecahedral; forms *f* (310), *e* (210) (fluoroids) common; also the vicinal form ζ (32·1·0?), producing striations on *a* (Fig. 640); hexoctahedron *t* (421) also common with the cube (Fig. 639). Cubic crystals sometimes grouped in parallel position, thus forming a pseudo-octahedron. Twins: tw. pl. *o*, commonly penetration-twins (Fig. 640). Also massive; granular, coarse or fine; rarely columnar; compact.

Cleavage: *o* perfect. Fracture flat-conchoidal; of compact kinds splintery. Brittle. H. = 4. G. = 3·01–3·25; 3·18 cryst. Luster vitreous. Color white, yellow, green, rose- and crimson-red, violet-blue, sky-blue, and brown; wine-yellow, greenish blue, violet-blue, most common; red, rare. Streak white. Transparent—subtranslucent. Sometimes shows a bluish fluorescence. Phosphoresces when heated (p. 191). Refractive index: n_y = 1·4339 Na.

Comp.—Calcium fluoride, CaF_2 = Fluorine 48·9, calcium 51·1 = 100. Chlorine is sometimes present in minute quantities.

Var.—1. *Ordinary;* (*a*) cleavable or crystallized, very various in colors; (*b*) fibrous to columnar, as the Derbyshire blue-john used for vases and other ornaments; (*c*) coarse to fine granular; (*d*) earthy, dull, and sometimes very soft. *Chlorophane* yields a green phosphorescent light.

Pyr., etc.—In the closed tube decrepitates and phosphoresces. B.B. in the forceps and on charcoal fuses, coloring the flame red, to an enamel which reacts alkaline on test paper. Fused in an open tube with fused salt of phosphorus gives the reaction for fluorine. Treated with sulphuric acid gives fumes of hydrofluoric acid which etch glass.

Diff.—Distinguished by its crystalline form, octahedral cleavage, relative softness (as compared with certain precious stones, also with the feldspars); etching power when treated with sulphuric acid. Does not effervesce with acid like calcite.

Obs.—Sometimes in beds, but generally in veins, in gneiss, mica slate, clay slate, and also in limestones, both crystalline and uncrystalline, and sandstones. Often occurs as the gangue of metallic ores, especially of lead. In the North of England, it is the gangue of the lead veins, which intersect the coal formation in Northumberland, Cumberland, Durham, and Yorkshire. In Derbyshire it is abundant, and also in Cornwall, where the veins intersect metamorphic rocks. The Cumberland and Derbyshire localities especially have afforded magnificent specimens. Common in the mining district of Saxony; fine near

Kongsberg in Norway. In the dolomites of St. Gothard occurs in pink octahedrons. Rarely in volcanic regions, as in the Vesuvian lava.

Some localities in the U. S. are, Trumbull, Conn. (*chlorophane*); Muscolonge Lake, Jefferson Co., N. Y., and Macomb, St. Lawrence Co., both in very large sea-green cubes; Franklin Furnace, N. J.; Amelia Court House, Va.; Gallatin Co., Ill.; St. Louis, Mo.

Hydrophilite. Chlorocalcite. Calcium chloride, $CaCl_2$. In white cubic crystals or as an incrustation at Vesuvius.

The following are from Vesuvius: **Chloromagnesite**, $MgCl_2$; **Scacchite**, $MnCl_2$; **Chloralluminite**, $AlCl_3 + xH_2O$; **Molysite**, $FeCl_3$.

Sellaite. Magnesium fluoride, MgF_2. In prismatic tetragonal crystals. H. = 5. G. = 2·97–3·15. Colorless. From the moraine of the Gebroulaz glacier in Savoy.

Lawrencite. Ferrous chloride, $FeCl_2$. Occurs in meteoric iron.

Cotunnite. Lead chloride, $PbCl_2$. In acicular crystals (orthorhombic) and in semi-crystalline masses. Soft. G· = 5·24. Color white, yellowish. From Vesuvius; also Tarapaca, Chili.

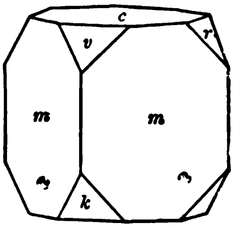
Tysonite. Fluoride of the cerium metals, $(Ce,La,Di)F_3$. In thick hexagonal prisms, and massive. Cleavage: *c* perfect. H. = 4·5–5. G. = 6·13. Color pale wax-yellow, changing to yellowish and reddish brown. From the granite of Pike's Peak, El Paso Co., Colorado.

CRYOLITE. Eisstein *Germ.*

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0·9663 : 1 : 1·3882$; $\beta = 89° 49'$.

mm''', $110 \wedge 1\bar{1}0 = 88°\ 2'$. *ck*, $001 \wedge \bar{1}01 = 55°\ 17'$.
cm, $001 \wedge 110 = 89°\ 52'$. *cr*, $001 \wedge 011 = 54°\ 14'$.
cv, $001 \wedge 101 = 55°\ 2'$. *cp*, $001 \wedge 111 = 63°\ 18'$.

641.



Crystals often cubic in aspect and grouped in parallel position; often with twin lamellæ. Massive, cleavable.

Cleavage: *c* most perfect, also *m*, *k* ($\bar{1}01$) somewhat less so. Fracture uneven. Brittle. H. = 2·5. G. = 2·95–3·0. Luster vitreous to greasy; somewhat pearly on *c*. Colorless to snow-white, sometimes reddish or brownish to brick-red or even black. Transparent to translucent.

Comp.—A fluoride of sodium and aluminium, Na_3AlF_6 or $3NaF.AlF_3$ = Fluorine 54·4, aluminium 12·8, sodium 32·8 = 100. A little iron sesquioxide is sometimes present as impurity.

Pyr., etc.—Fusible in small fragments in the flame of a candle. B.B. in the open tube heated so that the flame enters the tube gives off hydrofluoric acid, etching the glass. In the forceps fuses very easily, coloring the flame yellow. On charcoal fuses easily to a clear bead, which on cooling becomes opaque; after long blowing, the assay spreads out, the fluoride of sodium is absorbed by the coal, a suffocating odor of fluorine is given off, and a crust of alumina remains, which, when heated with cobalt solution in O.F., gives a blue color. Soluble in sulphuric acid, with evolution of hydrofluoric acid.

Diff.—Distinguished by its extreme fusibility, and its yielding hydrofluoric acid in the open tube. Also by its cleavages (resembling cubic cleavage) and softness.

Obs.—Occurs in a bay in Arksukfiord, in West Greenland, at Ivigtut (or Evigtok), about 12 m. from the Danish settlement of Arksuk, where it constitutes a large bed in a granitic vein in a gray gneiss. Cryolite and its alteration products, pachnolite, thomsenolite, prosopite, etc., also occur in limited quantity at the southern base of Pike's Peak, El Paso county, Colorado, north and west of Saint Peter's Dome.

Named from κρύος, *frost*, λίθος, *stone*, hence meaning *ice-stone*, in allusion to the translucency of the white cleavage masses.

Chiolite. $5NaF.3AlF_3$. In small pyramidal crystals (tetragonal); also massive granular. H. = 3·5–4. G. = 2·84–2·90. Color snow-white. From near Miask in the Ilmen Mts.; also with the Greenland cryolite.

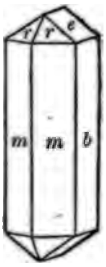
Hieratite. A fluoride of potassium and silicon. In grayish stalactitic concretions; isometric. From the fumaroles of the crater of Vulcano.

II. Oxychlorides, Oxyfluorides.

ATACAMITE.

Orthorhombic. **Axes** $\breve{a} : \bar{b} : \grave{c}$ = 0·6613 : 1 : 0·7515.

642.



mm'', 110 ∧ 110 = 66° 57'. *rr'''*, 111 ∧ $1\bar{1}1$ = 52° 48'.
ee', 011 ∧ $0\bar{1}1$ = 73° 51'. *mr*, 110 ∧ 111 = 36° 16½'.

Commonly in slender prismatic crystals, vertically striated. In confused crystalline aggregates; also massive, fibrous or granular to compact; as sand.

Cleavage: *b* highly perfect. Fracture conchoidal. Brittle. H. = 3–3·5. G. = 3·75–3·77. Luster adamantine to vitreous. Color bright green of various shades, dark emerald-green to blackish green. Streak apple-green. Transparent to translucent.

Comp.—$Cu_2ClH_3O_3$ or $CuCl_2.3Cu(OH)_2$ = Chlorine 16·6, copper 14·9, cupric oxide 55·8, water 12·7 = 100.

Pyr., etc.—In the closed tube gives off much water, and forms a gray sublimate. B.B. on charcoal fuses, coloring the O.F. azure-blue, with a green edge, and giving two coatings, one brownish and the other grayish white; continued blowing yields a globule of metallic copper; the coatings, touched with the R.F., volatilize, coloring the flame azure-blue. In acids easily soluble

Obs.—Originally from Atacama in the northern part of Chili; also found elsewhere in Chili and Bolivia; with malachite at Wallaroo in S. Australia; at St. Just in Cornwall. In the U. S., with cuprite, etc., at the United Verde mine, Jerome, Arizona.

Percylite. A lead-copper oxychloride, perhaps $PbCuO_2H_2Cl_2$. In sky-blue cubes. From Sonora, Mexico; Atacama; Bolivia, etc. *Boleite* from Boleo, near Santa Rosalia, Lower California, is a percylite containing a little silver. *Cumengite* is the same in crystals appearing to be tetragonal.

Matlockite. Lead oxychloride, Pb_2OCl_2. In tabular tetragonal crystals. G. = 7·21. Luster adamantine to pearly. Color yellowish or slightly greenish. From Cromford, near Matlock, Derbyshire.

Mendipite. $Pb_3O_2Cl_2$ or $PbCl_2.2PbO$. In fibrous or columnar masses; often radiated. H. = 2·5–3. G. = 7–7·1. Color white. From the Mendip Hills, Somersetshire, England; near Brilon, Westphalia.

Laurionite. PbClOH or $PbCl_2.Pb(OH)_2$. In minute prismatic colorless crystals (orthorhombic), in ancient lead slags at Laurion, Greece. **Fiedlerite**, associated with laurionite, is probably also a lead oxychloride; in colorless monoclinic crystals.

Penfieldite. Pb_3OCl_4 or $PbO.2PbCl_2$. In white hexagonal crystals. Laurion, Greece.

Daviesite. A lead oxychloride of uncertain composition. In minute colorless prismatic crystals (orthorhombic), from the Mina Beatriz, Sierra Gorda, Atacama.

Schwartzembergite. Probably $Pb(I,Cl)_2.2PbO$. In druses of small crystals; also in crusts. G. = 6·2. Color honey-yellow. Desert of Atacama.

Fluocerite. $(Ce,La,Di)_2OF_4$. Hexagonal. H. = 4. G. = 5·7–5·9. Color reddish yellow. From Österby in Dalarne, Sweden.

Nocerite. Perhaps $2(Ca,Mg)F_2(Ca,Mg)O$(?). In white hexagonal acicular crystals from bombs in the tufa of Nocera, Italy.

Daubreeite. An earthy yellowish oxychloride of bismuth. From Bolivia.

III. Hydrous Chlorides, Hydrous Fluorides, etc.

CARNALLITE.

Orthorhombic. Crystals rare. Commonly massive, granular.

No distinct cleavage. Fracture conchoidal. Brittle. H. = 1. G. = 1·60. Luster shining, greasy. Color milk-white, often reddish. Transparent to translucent. Strongly phosphorescent. Taste bitter. Deliquescent.

Comp.—$KMgCl_3.6H_2O$ or $KCl.MgCl_2 + 6H_2O$ = Chlorine 38·3, potassium 14·1, magnesium 8·7, water 39·0 = 100.

Obs.—Occurs at Stassfurt, in beds, alternating with thinner beds of common salt and kieserite.

DOUGLASITE, associated with carnallite, is said to be $2KCl.FeCl_2.2H_2O$.

Bischofite. $MgCl_2 + 6H_2O$. Crystalline-granular; colorless to white. From Leopoldshall, Prussia.

Kremersite. $KCl,NH_4Cl.FeCl_3 + H_2O$. In red octahedrons. From Vesuvius.

Erythrosiderite. $2KCl.FeCl_3.H_2O$. In red tabular crystals. Vesuvius.

Tachhydrite. $CaCl_2.2MgCl_2 + 12H_2O$. In wax- to honey-yellow masses. From Stassfurt.

Fluellite. $AlF_3 + H_2O$. In colorless or white rhombic pyramids. From Stenna Gwyn, Cornwall.

Prosopite. $CaF_2.2Al(F,OH)_3$. In monoclinic crystals, or granular massive. H. = 4·5. G. = 2·88. Colorless white, grayish. From Altenberg, Saxony; St. Peter's Dome near Pike's Peak, Colorado.

Pachnolite and **Thomsenolite**, occurring with cryolite in Greenland and Colorado, have the same composition, $NaF.CaF_2.AlF3 + H_2O$. Both occur in monoclinic prismatic crystals; prismatic angle for pachnolite, 98° 36′, crystals twins, orthorhombic in aspect. For thomsenolite, 89° 46′, crystals often resembling cubes (*m*, *c*), also prismatic; distinguished by its basal cleavage; also massive.

Gearksutite. $CaF_2.Al(F,OH)3.H_2O$. Earthy, clay-like. Occurs with cryolite.

Ralstonite. $(Na_2,Mg)F_2.3Al(F,OH)_3.2H_2O$. In colorless to white, isometric, octahedrons. H. = 4·5. G. = 2·56–2·62. With the Greenland cryolite.

Tallingite. A hydrated copper chloride from the Botallack mine, Cornwall; in blue globular crusts.

Footeite. A hydrous oxychloride of copper occurring in deep blue prismatic crystals (monoclinic) at the Copper Queen mine, Bisbee, Arizona.

Yttrocerite. $(Y,Er,Ce)F_3.5CaF_2.H_2O$. Massive-cleavable to granular and earthy. H. = 4–5. G. = 3·4. Color violet-blue, gray, reddish brown. From near Falun, Sweden, etc.

V. OXIDES.

I. Oxides of Silicon.

II. Oxides of the Semi-Metals: Tellurium, Arsenic, Antimony, Bismuth; also Molybdenum, Tungsten.

III. Oxides of the Metals.

The Fifth Class, that of the OXIDES, is subdivided into three sections, according to the positive element present. The oxides of the non-metal silicon are placed by themselves, but it will be noted that the compounds of the related element titanium are included with those of the metals proper. This last is made necessary by the fact that in one of its forms TiO_2 is isomorphous with MnO_2 and PbO_2.

A series of oxygen compounds which are properly to be viewed as salts, *e.g.*, the species of the Spinel Group and a few others, are for convenience also included in this class.

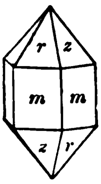
I. Oxides of Silicon.

QUARTZ.

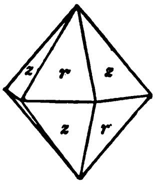
Rhombohedral-trapezohedral. Axis: $\dot{c} = 1\cdot09997$.

rr', $10\bar{1}1 \wedge \bar{1}101 = 85° 46'$.
rz, $10\bar{1}1 \wedge 01\bar{1}1 = 46° 16'$.
mr, $10\bar{1}0 \wedge 10\bar{1}1 = 38° 13'$.
mz, $10\bar{1}0 \wedge 01\bar{1}1 = 66° 52'$.
ms, $10\bar{1}0 \wedge 11\bar{2}1 = 37° 58'$.
mx, $10\bar{1}0 \wedge 51\bar{6}1 = 12° 1'$.

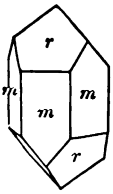
643.



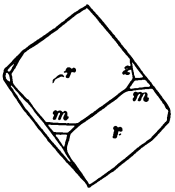
644.



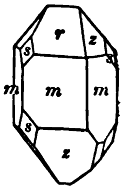
645.



646.

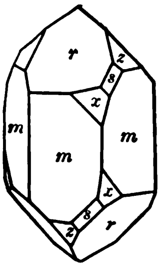


647.

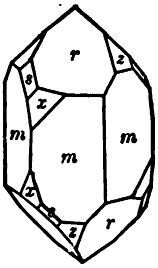


Crystals commonly prismatic, with the *m* faces horizontally striated; terminated either by both rhombohedrons, or by one only; the predominating rhombohedron is in almost all cases *r* ($10\bar{1}1$). Often in double six-sided pyramids or quartzoids through the equal development of *r* and *z*; when *r* is relatively large the form then has a cubic aspect ($rr' = 85° 46'$). Crystals frequently distorted, when the correct orientation may be obscure except as shown by the striations on *m*. Crystals often elongated to acicular forms, and tapering through the oscillatory combination of successive rhombohedrons with the prism. Occasionally twisted or bent. Frequently in radiated masses with a surface of pyramids, or in druses.

648.



649.

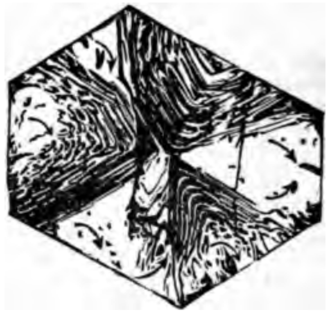


Simple crystals are either right- or left-handed. On a *right-handed* crystal (Fig. 648), *s*, if present, lies to the right of the *m* face, which is below the predominating plus rhombohedron *r*, and with this belong the plus right trapezohedrons, as *x*, and minus left trapezohedrons (cf. Fig. 270, p. 83), also *a* (left). On a *left-handed* crystal (Fig. 649), *s* lies to the left of the *m* below *r*, and with it the plus left and minus right trapezohedrons, also *a* (right). The right- and left-handed forms occur together only in twins. In the absence of trapezohedral faces the striations on *s* (∥ edge *r*/*m*), if distinct, serve to distinguish the faces *r* and *z*, and hence show the right- and left-handed character of the crystals. The right- and left-handed character is also revealed by etching (Art. **265**) and by pyro-electricity (Art. **420**).

Twins: (1) tw. axis $\dot{c}$, axes parallel. (2) Tw. pl. *a*, sometimes called the *Brazil law*, usually as irregular penetration-twins (Fig. 650). (3) Tw. pl. ξ (11$\bar{2}$2), contact-twins, the axes crossing at an angle of 84° 33′. See further p. 127 and Figs. 392–394. Massive forms common and in great variety, passing from the coarse or fine granular and crystalline kinds to those which are flint-like or cryptocrystalline. Sometimes mammillary, stalactitic, and in concretionary forms; as sand.

Cleavage not distinctly observed; sometimes fracture surfaces (∥ *r*, *z* and *m*) developed by sudden cooling after being heated (see Art. **258**). Fracture conchoidal to subconchoidal in crystallized forms, uneven to splintery in some massive kinds. Brittle to tough. H. = 7. G. = 2·653–2·660 in crystals; cryptocrystalline forms somewhat lower (to 2·60) if pure, but impure massive forms (*e.g.*, jasper) higher. Luster vitreous, sometimes greasy; splendent to nearly dull. Colorless when pure; often various shades of yellow, red, brown, green, blue, black. Streak white, of pure varieties; if impure, often the same as the color, but much paler. Transparent to opaque.

650.



Basal section in polarized light, showing interpenetration of right- and left-handed portions. Des Cloizeaux.

Optically +. Double refraction weak. Polarization circular; right-handed or left-handed, the optical character corresponding to right- and left-handed character of crystals, as defined above; in twins (law 2), both right and left forms sometimes united, sections then often showing Airy's spirals in the polariscope (cf. Art. **366**, p. 202, and Fig. 650). Rotatory power proportional to thickness of plate. Refractive indices for the D line, $\omega = 1·54418$, $\epsilon = 1·55328$; also rotatory power for section of $1^{\mathrm{mm.}}$ thickness, $\alpha = 21·71$ (D line). Pyroelectric; also electric by pressure or piezo-electric. See Arts. **420, 421.** On etching-figures, see Arts. **265, 266.**

Comp.—Silica, or silicon dioxide, SiO_2 = Oxygen 53·3, silicon 46·7 = 100.

In massive varieties often mixed with a little opal silica. Impure varieties contain iron oxide, calcium carbonate, clay, sand, and various minerals as inclusions.

Var.—1. PHENOCRYSTALLINE: Crystallized, vitreous in luster. 2. CRYPTOCRYSTALLINE: Flint-like, massive.

The first division includes all ordinary vitreous quartz, whether having crystalline faces or not. The varieties under the second are in general acted upon somewhat more by attrition, and by chemical agents, as hydrofluoric acid, than those of the first. In all kinds made up of layers, as agate, successive layers are unequally eroded.

A. PHENOCRYSTALLINE OR VITREOUS VARIETIES.

Ordinary Crystallized; Rock Crystal.—Colorless quartz, or nearly so, whether in distinct crystals or not. Here belong the Bristol diamonds, Lake George diamonds, Brazilian pebbles, etc. Some variations from the common type are: (*a*) cavernous crystals; (*b*) cap-quartz made up of separable layers or caps; (*c*) drusy quartz, a crust of small or minute quartz crystals; (*d*) radiated quartz, often separable into radiated parts having pyramidal terminations; (*e*) fibrous, rarely delicately so as a kind from Griqualand West, South Africa, altered from crocidolite (see *cat's-eye* below, also crocidolite p. 404).

Asteriated; Star-quartz.—Containing within the crystal whitish or colored radiations along the diametral planes. Occasionally exhibits distinct asterism.

Amethystine; Amethyst.—Clear purple, or bluish violet. Color perhaps due to manganese.

Rose.—Rose-red or pink, but becoming paler on exposure. Common massive. Luster sometimes a little greasy. Color perhaps due to titanium.

Yellow; False Topaz or *Citrine.*—Yellow and pellucid; resembling yellow topaz.

Smoky; Cairngorm Stone.—Smoky-yellow to dark smoky brown, and often transparent; varying to brownish black. Color is probably due to some organic compound (Forster). Called *cairngorms* from the locality at Cairngorm, S.W. of Banff, in Scotland. The name *morion* is given to nearly black varieties.

Milky.—Milk-white and nearly opaque. Luster often greasy.

Siderite, or *Sapphire-quartz.*—Of indigo or Berlin-blue color; a rare variety.

Sagenitic.—Inclosing acicular crystals of rutile. Other included minerals in acicular forms are: black tourmaline; göthite; stibnite; asbestus; actinolite; hornblende; epidote. *Cat's-Eye* (Katzenauge *Germ.*, Œil de Chat *Fr.*) exhibits opalescence, but without prismatic colors, especially when cut *en cabochon*, an effect sometimes due to fibers of asbestus. Also present in the siliceous pseudomorphs, after crocidolite, called *tiger-eye* (see crocidolite). The highly-prized Oriental cat's-eye is a variety of chrysoberyl.

Aventurine.—Spangled with scales of mica, hematite, or other mineral.

Impure from the presence of distinct minerals distributed densely through the mass. The more common kinds are those in which the impurities are: (*a*) *ferruginous* (Eisenkiesel *Germ.*), either red or yellow, from anhydrous or hydrous iron sesquioxide; (*b*) *chloritic*, from some kind of chlorite; (*c*) *actinolitic;* (*d*) *micaceous;* (*e*) *arenaceous*, or sand.

Containing liquids in cavities. The liquid usually water (pure, or a mineral solution), or some petroleum-like compound. Quartz, especially smoky quartz, also often contains inclusions of both liquid and gaseous carbon dioxide.

B. CRYPTOCRYSTALLINE VARIETIES.

Chalcedony.—Having the luster nearly of wax, and either transparent or translucent. G. = 2·6–2·64. Color white, grayish, blue, pale brown to dark brown, black. Also of other shades, and then having other names. Often mammillary, botryoidal, stalactitic, and occurring lining or filling cavities in rocks. It often contains some disseminated opal-silica. The name *enhydros* is given to nodules of chalcedony containing water, sometimes in large amount. Embraced under the general name chalcedony is the crystalline form of silica which forms concretionary masses with radial-fibrous and concentric structure, and which, as shown by Rosenbusch, is optically *negative*, unlike true quartz. It has $n_r = 1{\cdot}537$; G. = 2·59–2·64. Often in spherulites, showing the spherulitic interference-figure. *Lussatite* of Mallard has a like structure, but is optically + and has the specific gravity and refractive index of opal. See also quartzine, p. 328.

Carnelian. Sard.—A clear red chalcedony, pale to deep in shade; also brownish red to brown.

Chrysoprase.—An apple-green chalcedony, the color due to nickel oxide.

Prase.—Translucent and dull leek-green.

Plasma.—Rather bright green to leek-green, and also sometimes nearly emerald-green, and subtranslucent or feebly translucent. *Heliotrope*, or *Blood-stone*, is the same stone essentially, with small spots of red jasper, looking like drops of blood.

Agate.—A variegated chalcedony. The colors are either (*a*) banded; or (*b*) irregularly clouded; or (*c*) due to visible impurities as in moss agate, which has brown moss-like or dendritic forms, as of manganese oxide, distributed through the mass. The bands are delicate parallel lines, of white, pale and dark brown, bluish and other shades; they are sometimes straight, more often waving or zigzag, and occasionally concentric circular. The bands are the edges of layers of deposition, the agate having been formed by a deposit of silica from solutions intermittently supplied, in irregular cavities in rocks, and deriving their concentric waving courses from the irregularities of the walls of the cavity. The layers differ in porosity, and therefore agates may be varied in color by artificial means, and this is done now to a large extent with the agates cut for ornament. There is also *agatized wood:* wood petrified with clouded agate.

Onyx.—Like agate in consisting of layers of different colors, white and black, white and red, etc., but the layers in even planes, and the banding straight, and hence its use for cameos.

Sardonyx.—Like onyx in structure, but includes layers of carnelian (sard) along with others of white or whitish, and brown, and sometimes black colors.

Agate-jasper.—An agate consisting of jasper with veinings of chalcedony.

Siliceous sinter.—Irregularly cellular quartz, formed by deposition from waters containing silica or soluble silicates in solution. See also under opal, p. 329.

Flint.—Somewhat allied to chalcedony, but more opaque, and of dull colors, usually gray, smoky brown, and brownish black. The exterior is often whitish, from mixture with lime or chalk, in which it is embedded. Luster barely glistening, subvitreous. Breaks with a deeply conchoidal fracture, and a sharp cutting edge. The flint of the chalk formation consists largely of the remains of diatoms, sponges, and other marine productions. The coloring matter of the common kinds is mostly carbonaceous matter. Flint implements play an important part among the relics of early man.

Hornstone.—Resembles flint, but is more brittle, the fracture more splintery. *Chert* is a term often applied to hornstone, and to any impure flinty rock, including the jaspers.

Basanite; Lydian Stone, or *Touchstone.*—A velvet-black siliceous stone or flinty jasper, used on account of its hardness and black color for trying the purity of the precious metals. The color left on the stone after rubbing the metal across it indicates to the experienced eye the amount of alloy. It is not splintery like hornstone.

Jasper.—Impure opaque colored quartz; commonly red, also yellow, dark green and grayish blue. *Striped* or *riband jasper* has the colors in broad stripes. *Porcelain jasper* is nothing but baked clay, and differs from true jasper in being B.B. fusible on the edges.

C. Besides the above there are also:

Granular Quartz, Quartz-rock, or *Quartzite.*—A rock consisting of quartz grains very firmly compacted; the grains often hardly distinct. *Quartzose Sandstone, Quartz-conglomerate.*—A rock made of pebbles of quartz with sand. The pebbles sometimes are jasper and chalcedony, and make a beautiful stone when polished. *Itacolumite,* or *Flexible Sandstone.*—A friable sand-rock, consisting mainly of quartz-sand, but containing a little mica, and possessing a degree of flexibility when in thin laminæ. *Buhrstone,* or Burrstone. —A cellular, flinty rock, having the nature in part of coarse chalcedony.

Pseudomorphous Quartz.—Quartz appears also under the forms of many of the mineral species, which it has taken through either the alteration or replacement of crystals of those species. The most common quartz pseudomorphs are those of calcite, barite, fluorite, and siderite. *Silicified wood* is quartz pseudomorph after wood (p. 258).

Pyr., etc.—B.B. unaltered; with borax dissolves slowly to a clear glass; with soda dissolves with effervescence; unacted upon by salt of phosphorus. Insoluble in hydrochloric acid, and only slightly acted upon by solutions of fixed caustic alkalies, the crypto-crystalline varieties to the greater extent. Soluble only in hydrofluoric acid. When fused and cooled it becomes opal-silica having G. $= 2{\cdot}2$.

Diff.—Characterized in crystals by the form, glassy luster, and absence of cleavage; also in general by hardness and infusibility.

Easily recognized in rock sections by its low refraction ("low relief," p. 170) and low birefringence ($\epsilon - \omega = 0{\cdot}009$); the interference colors in good sections not rising above yellow of the first order; also by its limpidity and the positive uniaxial cross yielded by axial sections (p. 203, note), which remain dark when revolved between crossed nicols. Commonly in formless grains (granite), also with crystal outline (porphyry, etc.).

Obs.—*Quartz* is an essential component of certain igneous rocks, as granite, granite-porphyry, quartz-porphyry and rhyolite in the granite group; in such rocks it is commonly in formless grains or masses filling the interstices between the feldspar, as the last product of crystallization. Further it is an essential constituent in quartz-diorite, quartz-diorite porphyry and dacites in the diorite group; in the porphyries frequently in distinct crystals. It occurs also as an accessory in other feldspathic igneous rocks, such as syenite and trachyte. Among the metamorphic rocks it is an essential component of certain varieties of gneiss, of quartzite, etc. It forms the mass of common sandstone. It occurs as the vein-stone in various rocks, and for a large part of mineral veins; as a foreign mineral in some limestones, etc., making geodes of crystals, or of chalcedony, agate, carnelian, etc.; as embedded nodules or masses in various limestones, constituting the flint of the Chalk formation, the hornstone of other limestones—these nodules sometimes becoming continuous layers; as masses of jasper occasionally in limestone. It is the principal material of the pebbles of gravel-beds, and of the sands of the seashore, and sandbeds everywhere. In graphic granite (*pegmatite*) the quartz individuals are arranged in parallel position in feldspar, the angular particles resembling written characters. The quartz grains in a fragmental sandstone are often found to have undergone a secondary growth by the deposition of crystallized silica with like orientation to the original nucleus.

Switzerland Dauphiné, Piedmont, the Carrara quarries, and numerous other foreign localities, afford fine specimens of rock crystal; also Japan, whence the beautiful crystal spheres, in rare cases up to 6 inches in diameter. *Smoky quartz* crystals of great beauty, and often highly complex in form, occur at many points in the central Alps, also at Cairngorm, Scotland. The most beautiful amethysts are brought from India, Ceylon, and Persia, also from Brazil; inferior specimens occur in Transylvania. The finest *carnelians* and *agates* are found in Arabia, India, Brazil, Surinam, also formerly at Oberstein and Saxony. Scotland affords smaller but handsome specimens (Scotch pebbles). The banks of the Nile afford the Egyptian jasper; the striped jasper is met with in Siberia, Saxony, and Devonshire.

In New York, quartz crystals are abundant in Herkimer Co., at Middleville, Little Falls, etc., loose in cavities in the Calciferous sand-rock, or embedded in loose earth. Fine quartzoids, at the beds of hematite in Fowler, Herman, and Edwards, St. Lawrence Co., also at Antwerp, Jefferson Co. On the banks of Laidlaw Lake, Rossie, large implanted crystals; at Ellenville lead mine, Ulster Co , in fine groups. At Paris, Me., handsome crystals of brown or smoky quartz. Beautiful colorless crystals occur at Hot Springs, Arkansas. Alexander Co., N. C., has afforded great numbers of highly complex crystals, with rare modifications. Fine crystals of smoky quartz come from the granite of the Pike's Peak region, Colorado. Geodes of quartz crystals, also enclosing calcite, sphalerite, etc., are common in the Keokuk limestone of the west.

Rose quartz occurs at Albany and Paris, Me.; Acworth, N.; H. Southbury, Conn. *Amethyst*, in trap, at Keweenaw Point, Lake Superior; Specimen Mt , Yellowstone Park; in Pennsylvania, in East Bradford, Chester, and Providence (one fine crystal over 7 lbs. in weight), in Chester Co.; at the Prince vein, Lake Superior; large crystals, near Greensboro, N. C.; crystallized green quartz, in talc, at Providence, Delaware Co., Penn. *Chalcedony* and *agates* abundant and beautiful on N. W. shore of Lake Superior. Red jasper is found on Sugar Loaf Mt., Maine; in pebbles on the banks of the Hudson at Troy; yellow, with chalcedony, at Chester, Mass. Agatized and jasperized wood of great beauty and variety of color is obtained from the petrified forest called Chalcedony Park, near Carrizo, Apache Co., Arizona; also from the Yellowstone Park; near Florissant and elsewhere in Colorado; Amethyst Mt., Utah; Napa Co., California. Moss agates from Humboldt Co., Nevada, and many other points.

The word quartz is of German provincial origin. Agate is from the name of the river Achates, in Sicily, whence specimens were brought, as stated by Theophrastus.

QUARTZINE is a name which has been given to a form of silica which is present in chalcedony and is inferred to be triclinic in crystalline structure. *Lutecite* belongs here.

TRIDYMITE.

Hexagonal or pseudo-hexagonal. Axis $\dot{c} = 1{\cdot}6530$. Crystals usually minute, thin tabular ‖ *c*; often in twins; also united in fan-shaped groups.

Cleavage: prismatic, not distinct; parting ‖ *c*, sometimes observed. Fracture conchoidal. Brittle. H. = 7. G. = 2·28–2·33. Luster vitreous, on *c* pearly. Colorless to white. Transparent. Optically +. Often exhibits anomalous refraction phenomena.

Comp.—Pure silica, SiO_2, like quartz.

Pyr., etc.—Like quartz, but soluble in boiling sodium carbonate.

Obs.—Occurs chiefly in acidic volcanic rocks, trachyte, andesite, liparite, less often in dolerite; usually in cavities, often associated with sanidine, also hornblende, augite, hematite; sometimes in opal. First observed in crevices and druses in an augite-andesite from the Cerro San Cristobal, near Pachuca, Mexico; later proved to be rather generally distributed. Thus in trachyte of the Siebengebirge; of Euganean Hills in N. Italy; Puy Capucin (Mont-Dore) in Central France, etc In the ejected masses from Vesuvius consisting chiefly of sanidine. With quartz, feldspar, fayalite in lithophyses of Obsidian cliff, Yellowstone Park. In the andesite of Mt. Rainier, Washington.

Named from τρίδυμος, *threefold*, in allusion to the common occurrence in trillings.

ASMANITE. A form of silica found in the meteoric iron of Breitenbach, in very minute grains, probably identical with tridymite; by some referred to the orthorhombic system.

CRISTOBALITE. Christobalite. Silica in white octahedrons (pseudo-isometric?). G. = 2·27. With tridymite in andesite of the Cerro S. Cristobal, Pachuca, Mexico.

MELANOPHLOGITE. In minute cubes and spherical aggregates. Occurring with calcite and celestite implanted upon an incrustation of opaline silica over the sulphur crystals of Girgenti, Sicily. Consists of SiO_2 with 5 to 7 p. c. of SO_3. The mineral turns black superficially when heated B.B.

OPAL.

Amorphous. Massive; sometimes small reniform, stalactitic, or large tuberose. Also earthy.

H. = 5·5–6·5. G. = 1·9–2·3; when pure 2·1–2·2. Luster vitreous, frequently subvitreous; often inclining to resinous, and sometimes to pearly. Color white, yellow, red, brown, green, gray, blue, generally pale; dark colors arise from foreign admixtures; sometimes a rich play of colors, or different colors by refracted and reflected light. Streak white. Transparent to nearly opaque. $n_r = 1·44–1·45$.

Often shows double refraction similar to that observed in colloidal substances due to tension. The cause of the play of color in the precious opal was investigated by Brewster, who ascribed it to the presence of microscopic cavities. Behrends, however, has given a monograph on the subject (Ber. Ak. Wien, **64** (1), 1871), and has shown that this explanation is incorrect; he refers the colors to thin curved lamellæ of opal whose refractive power may differ by 0·1 from that of the mass. These are conceived to have been originally formed in parallel position, but have been changed, bent, and finally cracked and broken in the solidification of the groundmass.

Comp.—Silica, like quartz, with a varying amount of water, $SiO_2.nH_2O$. The water is sometimes regarded as non-essential.

The opal condition is one of lower degrees of hardness and specific gravity, and, as generally believed, of incapability of crystallization. The water present varies from 2 to 18 p. c. or more, but mostly from 3 to 9 p. c. Small quantities of ferric oxide, alumina, lime, magnesia, and alkalies are usually present as impurities.

Var.—*Precious Opal.*—Exhibits a play of delicate colors.

Fire-opal.—Hyacinth-red to honey-yellow colors, with fire-like reflections, somewhat irised on turning.

Girasol.—Bluish white, translucent, with reddish reflections in a bright light.

Common Opal.—In part translucent; (*a*) *milk-opal*, milk-white to greenish, yellowish, bluish; (*b*) *Resin-opal*, wax-, honey- to ocher-yellow, with a resinous luster; (*c*) dull olive-green and mountain-green; (*d*) brick-red. Includes *Semiopal*; (*e*) *Hydrophane*, a variety which becomes more translucent or transparent in water.

Cacholong.—Opaque, bluish white, porcelain-white, pale yellowish or reddish.

Opal-agate.—Agate-like in structure, but consisting of *opal* of different shades of color.

Menilite.—In concretionary forms; opaque, dull grayish.

Jasp-opal. Opal jasper.—Opal containing some yellow iron oxide and other impurities, and having the color of yellow jasper, with the luster of common opal.

Wood-opal. Holz-opal *Germ.*—Wood petrified by opal.

Hyalite. Muller's Glass.—Clear as glass and colorless, constituting globular concretions, and crusts with a globular or botryoidal surface; also passing into translucent, and whitish. Less readily dissolved in caustic alkalies than other varieties.

Fiorite, Siliceous Sinter.—Includes translucent to opaque, grayish, whitish or brownish incrustations, porous to firm in texture; sometimes fibrous-like or filamentous, and, when so, pearly in luster (then called *Pearl-sinter*); deposited from the siliceous waters of hot springs.

Geyserite.—Constitutes concretionary deposits about the geysers of the Yellowstone Park, Iceland, and New Zealand, presenting white or grayish, porous, stalactitic, filamentous, cauliflower like forms, often of great beauty; also compact-massive, and scaly-massive.

Float stone.—In light porous concretionary masses, white or grayish, sometimes cavernous, rough in fracture.

Tripolite.—Formed from the siliceous shells of diatoms (hence called *diatomite*) and other microscopic species, and occurring in extensive deposits. Includes *Infusorial Earth*, or *Earthy Tripolite*, a very fine-grained earth looking often like an earthy chalk, or a clay, but harsh to the feel, and scratching glass when rubbed on it.

Pyr., etc.—Yields water. B.B. infusible, but becomes opaque. Some yellow varieties, containing iron oxide, turn red. Soluble in hydrofluoric acid somewhat more readily than quartz; also soluble in caustic alkalies, but more readily in some varieties than in others.

Obs.—Occurs filling cavities and fissures or seams in igneous rocks, as trachyte, porphyry, also in some metallic veins. Also embedded, like flint, in limestone, and sometimes, like other quartz concretions, in argillaceous beds; formed from the siliceous waters of some hot springs; often resulting from the mere accumulation, or accumulation and partial solution and solidification, of the siliceous shells of infusoria, of sponge spicules, etc., which consist essentially of opal-silica. The last mentioned is the probable source of the opal of limestones and argillaceous beds (as it is of flint in the same rocks), and of part of that in igneous rocks. It exists in most chalcedony and flint.

Precious opal occurs in porphyry at Czerwenitza, near Kashau in Hungary; at Gracias a Dios in Honduras; Queretaro in Mexico; a beautiful blue opal on Bulla Creek, Queensland. *Fire-opal* occurs at Zimapan in Mexico; the Färöer; near San Antonio, Honduras. *Common opal* is abundant at Telkebánya in Hungary; near Pernstein, etc., in Moravia; in Bohemia; Steuzelberg in Siebengebirge; in Iceland. *Hyalite* occurs in amygdaloid at Schemnitz, Hungary; in clinkstone at Waltsch, Bohemia; at San Luis Potosi, Mexico.

In U. S., *hyalite* occurs sparingly in connection with the trap rock of New Jersey and Connecticut. A water-worn specimen of fire-opal has been found on the John Davis river, in Crook Co., Oregon.

Common opal is found at Cornwall, Lebanon Co, Penn.; at Aquas Calientes, Idaho Springs, Colo.; a white variety at Mokelumne Hill, Calaveras Co., Cal., and on the Mt. Diablo range. Geyserite occurs in great abundance and variety in the Yellowstone region (cf. above); also siliceous sinter at Steamboat Springs, Nevada. Other localities are given by Kunz, Gems and Precious Stones of N. A., 1890.

II. Oxides of the Semi-Metals; also Molybdenum, Tungsten.

Arsenolite. Arsenic trioxide, As_2O_3. In isometric octahedrons; in crusts and earthy. Colorless or white. G. = 3·7. Occurs with arsenical ores.

Claudetite. Also As_2O_3, but monoclinic in form.

Senarmontite. Antimony trioxide. Sb_2O_3. In isometric octahedrons; in crusts and granular massive. G. = 5·3. Colorless, grayish. Occurs with ores of antimony.

Valentinite. Also Sb_2O_3, but in prismatic orthorhombic crystals.

Bismite.. Bismuth trioxide, Bi_2O_3. Pulverulent, earthy; color straw-yellow.

Tellurite. Tellurium dioxide, TeO_2. In white to yellow slender prismatic crystals.

Molybdite. Molybdenum trioxide, MoO_3. In capillary tufted forms and earthy. Color straw-yellow.

Tungstite. Tungsten trioxide, WO_3. Pulverulent, earthy; color yellow or yellowish green.

Cervantite. $Sb_2O_3.Sb_2O_5$. In yellow to white acicular crystals; also massive, pulverulent.

Stibiconite. $H_2Sb_2O_5$. Massive, compact. Color pale yellow to yellowish white.

III. Oxides of the Metals.

A. Anhydrous Oxides.

I. **Protoxides,** R_2O and RO.

II. **Sesquioxides,** R_2O_3.

III. **Intermediate,** $\overset{II}{R}\overset{III}{R}_2O_4$ or $RO.R_2O_3$, etc.

IV. **Dioxides,** RO_2.

The Anhydrous Oxides include, as shown above, three distinct divisions, the Protoxides, the Sesquioxides and the Dioxides. The remaining Intermediate division embraces a number of oxygen compounds which are properly to be regarded chemically as salts of certain acids (aluminates, ferrates, etc.); here is included the well-characterized SPINEL GROUP.

Among the Protoxides the only distinct group is the PERICLASE GROUP, which includes the rare species Periclase, MgO, Manganosite, MnO, and Bunsenite, NiO. All of these are isometric in crystallization.

The Sesquioxides include the well-characterized HEMATITE GROUP, R_2O_3. The Dioxides include the prominent RUTILE GROUP, RO_2. Both of these groups are further defined later.

---

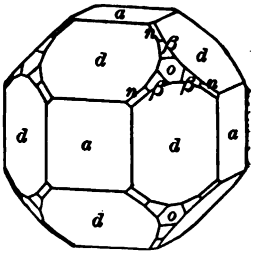
1. Protoxides, R_2O and RO.

CUPRITE. Red Copper Ore. Rothkupfererz *Germ.*

Isometric-plagihedral. Commonly in octahedrons; also in cubes and dodecahedrons, often highly modified. Plagihedral faces sometimes distinct (see pp. 50, 51). Also massive, granular; sometimes earthy.

Cleavage: *o* interrupted. Fracture conchoidal, uneven. Brittle. H. = 3·5–4. G. = 5·85–6·15. Luster adamantine or submetallic to earthy. Color red, of various shades, particularly cochineal-red, sometimes almost black; occasionally crimson-red by transmitted light. Streak several shades of brownish red, shining. Subtransparent to subtranslucent. Refractive index, n_r = 2·849 Fizeau.

651.



Arizona.

Var.—1. *Ordinary.* (*a*) Crystallized; commonly in octahedrons, dodecahedrons, cubes, and intermediate forms; the crystals often with a crust of malachite; (*b*) massive.

2. *Capillary; Chalcotrichite.* Plush Copper Ore. In capillary or acicular crystallizations, which are sometimes cubes elongated in the direction of the cubic axis.

3. *Earthy; Tile Ore,* Ziegelerz *Germ.* Brick-red or reddish brown and earthy, often mixed with red oxide of iron; sometimes nearly black.

Comp.—Cuprous oxide, Cu_2O = Oxygen 11·2, copper 88·8 = 100.

Pyr., etc.—Unaltered in the closed tube. B.B. in the forceps fuses and colors the flame emerald-green. On charcoal first blackens, then fuses, and is reduced to metallic copper. With the fluxes gives reactions for copper. Soluble in concentrated hydrochloric acid, and a strong solution when cooled and diluted with cold water yields a heavy, white precipitate of subchloride of copper.

Diff.—Distinguished from hematite by inferior hardness, but is harder than cinnabar and proustite and differs from them in the color of the streak; reactions for copper, B.B., are conclusive.

Obs.—Occurs at Kamsdorf in Thuringia; in Cornwall, in fine crystals, at Wheal Gorland and other mines; in Devonshire near Tavistock; in isolated crystals, more or less altered to malachite, at Chessy, near Lyons, France; in the Ural; South Australia; also abundant in Chili, Peru, Bolivia.

In the U. S. observed at Somerville, etc., N. J.; at Cornwall, Lebanon Co., Pa.; in the Lake Superior region. With malachite, limonite, etc., at the Copper Queen mine, Bisbee, Arizona, sometimes in fine crystals; beautiful *chalcotrichite* at Morenci; at Clifton, Graham Co., in crystals, and massive.

Ice. H_2O. Hexagonal. Familiarly known in six-rayed snow crystals; also coating ponds in winter, further as glaciers and icebergs.

Periclase Group.

Periclase. Magnesia, MgO. In cubes or octahedrons, and in grains. Cleavage cubic. H. = 6. G. = 3·67–3·90. Occurs in white limestone at Mt. Somma; at the Kitteln manganese mine, Nordmark, Sweden.

Manganosite. Manganese protoxide, MnO. In isometric octahedrons. Cleavage cubic. H. = 5-6. G. = 5·18. Color emerald-green, becoming black on exposure. From Långban and Nordmark, Sweden.

Bunsenite. Nickel protoxide, NiO. In green octahedrons. From Johanngeorgenstadt.

ZINCITE. Red Oxide of Zinc. Red Zink Ore. Rothzinkerz *Germ.*

Hexagonal-hemimorphic. Axis $\dot{c} = 1·6219$. Natural crystals rare (Fig. 50, p. 18); usually foliated massive, or in coarse particles and grains; also with granular structure.

Cleavage: *c* perfect; prismatic, sometimes distinct. Fracture subconchoidal. Brittle. H. = 4–4·5. G. = 5·43–5·7. Luster subadamantine. Streak orange-yellow. Color deep red, also orange-yellow. Translucent to subtranslucent. Optically +.

Comp.—Zinc oxide, ZnO = Oxygen 19·7, zinc 80·3 = 100. Manganese protoxide is sometimes present.

Pyr., etc.—B.B. infusible; with the fluxes, on the platinum wire, gives reactions for manganese, and on charcoal in R.F. gives a coating of zinc oxide, yellow while hot, and white on cooling. The coating, moistened with cobalt solution and treated in O.F., assumes a green color. Soluble in acids.

Diff.—Characterized by its color, particularly that of the streak; by cleavage; by reactions B.B.

Obs.—Occurs with franklinite and willemite, at Sterling Hill near Ogdensburg, and at Mine Hill, Franklin Furnace, Sussex Co., N. J., sometimes in lamellar masses in pink calcite. A not uncommon furnace product.

Massicot. Lead monoxide, PbO. Massive, scaly or earthy. Color yellow, reddish.

Tenorite. Cupric oxide, CuO. In minute black scales with metallic luster; from Vesuvius. Also black earthy massive (*melaconite*); occurring with ores of copper as at Ducktown, Tenn., and Keweenaw Point, Lake Superior.

Paramelaconite is essentially cupric oxide, CuO, occurring in black pyramidal crystals referred to the tetragonal system. From the Copper Queen mine, Bisbee, Arizona.

Hematite Group. R_2O_3. Rhombohedral.

			rr'	$\dot{c}$
Corundum	Al_2O_3		93° 56′	1·3630
Hematite	Fe_2O_3		94° 0′	1·3656
Ilmenite	$(Fe,Mg)O.TiO_2$	Tri-rhombohedral	94° 29′	1·3846
Pyrophanite	$MnO.TiO_2$	"	94° 5½′	1·3692

The HEMATITE GROUP embraces the sesquioxides of aluminium and iron. These compounds crystallize in the rhombohedral system with a fundamental rhombohedron differing but little in angle from a cube. Both the minerals belonging here, Hematite and Corundum, are *hard*.

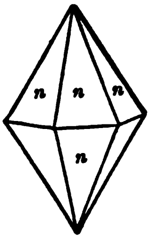
To these species the titanates of iron (and magnesium) and manganese, Ilmenite and Pyrophanite, are closely related in form though belonging to the tri-rhombohedral group (phenacite type); in other words, the relation between hematite and ilmenite may be regarded as analogous to that between calcite and dolomite. It is to be noted, further, that hematite often contains titanium, and an artificial isomorphous compound, Ti_2O_3, has been described. Hence the ground for writing the formula of ilmenite $(Fe,Ti)_2O_3$, as is done by some authors. It is shown by Penfield, however, that the formula $(Fe,Mg)TiO_3$ is more correct.

CORUNDUM.

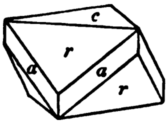
Rhombohedral. Axis $\dot{c} = 1·3630$.

cr, $0001 \wedge 10\bar{1}1 = 57° \; 34'$.
cn, $0001 \wedge 22\bar{4}3 = 61° \; 11'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 93° \; 56'$.
nn', $2243 \wedge \bar{2}4\bar{2}3 = 51° \; 58'$.
vv', $·44\bar{8}3 \wedge 4\bar{8}43 = 57° \; 38'$.
zz', $2241 \wedge \bar{2}4\bar{2}1 = 58° \; 55'$.

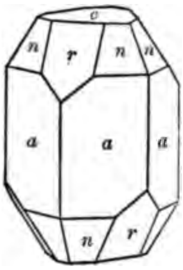
652.



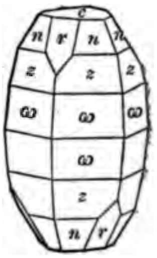
653.



654.



655.



Twins: tw. pl. *r*; sometimes penetration-twins; often polysynthetic, and thus producing a laminated structure. Crystals usually rough and rounded. Also massive, with nearly rectangular parting or pseudo-cleavage; granular, coarse or fine.

Parting: *c*, sometimes perfect, but interrupted; also *r* due to twinning, often prominent; *a* less distinct. Fracture uneven to conchoidal. Brittle, when compact very tough. H. = 9. G. = 3·95–4·10. Luster adamantine to vitreous; on *c* sometimes pearly. Occasionally showing asterism. Color blue, red, yellow, brown, gray, and nearly white; streak uncolored. Pleochroic in deeply colored varieties. Transparent to translucent. Normally uniaxial, negative; for sapphire $\omega_r = 1·7676$ to $1·7682$ and $\epsilon_r = 1·7594$ to $1·7598$ Dx. Often abnormally biaxial.

Var.—There are three subdivisions of the species prominently recognized in the arts, but differing only in purity and state of crystallization or structure.

VAR. 1. SAPPHIRE, RUBY.—Includes the purer kinds of fine colors, transparent to translucent, useful as gems Stones are named according to their colors: *Sapphire* blue: true *Ruby*, or *Oriental Ruby*, red; *O. Topaz*, yellow; *O. Emerald*, green; *O. Amethyst*, purple. A variety having a stellate opalescence when viewed in the direction of the vertical axis of the crystal, is the *Asteriated* Sapphire or Star Sapphire.

2. CORUNDUM.—Includes the kinds of dark or dull colors and not transparent, colors light blue to gray, brown, and black. The original *adamantine spar* from India has a dark grayish smoky-brown tint, but greenish or bluish by transmitted light, when translucent.

3 EMERY. Schmirgel *Germ.*—Includes granular corundum, of black or grayish black color, and contains magnetite or hematite intimately mixed. Sometimes associated with iron spinel or hercynite. Feels and looks much like a black fine-grained iron ore, which it was long considered to be. There are gradations from the evenly fine grained emery to kinds in which the corundum is in distinct crystals.

Comp.—Alumina, Al_2O_3 = Oxygen 47·1, aluminium 52·9 = 100. The crystallized varieties are essentially pure; analyses of emery show more or less impurity, chiefly magnetite.

Pyr., etc.—B.B. unaltered; slowly dissolved in borax and salt of phosphorus to a clear glass, which is colorless when free from iron; not acted upon by soda. The finely pulverized mineral, after long heating with cobalt solution, gives a beautiful blue color. Not acted upon by acids, but converted into a soluble compound by fusion with potassium bisulphate.

Diff.—Characterized by its hardness (scratching quartz and topaz), by its adamantine luster, high specific gravity and infusibility. The massive variety with rhombohedral parting resembles cleavable feldspar but is much harder and denser.

Obs.—Usually occurs in crystalline rocks, as granular limestone or dolomite, gneiss, granite, mica slate, chlorite slate. The associated minerals often include some species of the chlorite group, as prochlorite, corundophilite, margarite, also tourmaline, spinel, cyanite, diaspore, and a series of aluminous minerals, in part produced from its alteration. Occasionally found in ejected masses enclosed in younger volcanic rocks, as at Königswinter, Niedermendig, etc. Rarely observed as a contact-mineral. The fine sapphires are usually obtained from the beds of rivers, either in modified hexagonal prisms or in rolled masses, accompanied by grains of magnetite, and several kinds of gems, as spinel, etc. The emery of Asia Minor, Dr. Smith states, occurs in granular limestone.

The best rubies come from the mines in Upper Burma, north of Mandalay, in an area covering 25 to 30 square miles, of which Mogok is the center. The rubies occur *in situ* in crystalline limestone, also in the soil of the hillsides and in gem-bearing gravel. Blue sapphires are brought from Ceylon, often as rolled pebbles, also as well-preserved crystals. Corundum occurs in the Carnatic on the Malabar coast, on the Chantibun hills in Siam, and elsewhere in the East Indies; also near Canton, China. At St. Gothard, it occurs of a red or blue tinge in dolomite, and near Mozzo in Piedmont, in white compact feldspar. Adamantine spar is met with in large coarse, hexagonal pyramids in Gellivara, Sweden. Other localities are in Bohemia, near Petschau; in the Ilmen mountains, not far from Miask; in the gold-washings northeast of Zlatoust. Corundum, sapphires, and less often rubies occur in rolled pebbles in the diamond gravels on the Cudgegong river, at Mudgee and other points in New South Wales. Emery is found in large bowlders at Naxos, Nicaria, and Samos of the Grecian islands; also in Asia Minor, 12 m. E. of Ephesus, near Gumuchdagh and near Smyrna, associated with margarite, chloritoid, pyrite.

In N. America, in ***Massachusetts***, at Chester, with magnetite, diaspore, ripidolite, margarite, etc., mined for use as emery. In *Connecticut*, near Litchfield. In *New York*, at Warwick, bluish and pink, with spinel; Amity, in gran. limestone; emery with magnetite and green spinel (hercynite) in Westchester Co., near Cruger's Station, and elsewhere. In *New Jersey*, at Newton, blue crystals in gran. limestone; at Vernon. In *Pennsylvania*, in Delaware Co., in Aston, near Village Green, in large crystals; at Mineral Hill, in loose cryst.; in Chester Co., at Unionville, abundant in crystals; in large crystals loose in the soil at Shimersville, Lehigh Co. In *Virginia*, in the mica schists of Bull Mt., Patrick Co.

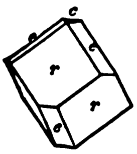
Common at many points along a belt extending from Virginia across western North and South Carolina and Georgia to Dudleyville, Alabama; especially in Madison, Buncombe, Haywood, Jackson, Macon, Clay, and Gaston counties in North Carolina. The localities at which most work has been done are the Culsagee mine, Corundum hill, near Franklin, Macon Co., N. C., and 26 miles S. E. of this, at Laurel Creek, Ga. The corundum occurs in beds in chrysolite (and serpentine) and hornblendic gneiss, associated with a species of the chlorite group, also spinel, etc., and here as elsewhere with many minerals resulting from its alteration. Some fine rubies have been found. Fine pink crystals of corundum occur at Hiawassee, Towns Co., Georgia. In *Colorado*, small blue crystals occur in mica schist near Salida, Chaffee Co. Gem sapphires are found near Helena, Montana, in gold-washings and in bars in the Missouri river, especially the Eldorado bar; at Yogo Gulch on the Judith river and at other points in Montana. In *California*, in Los Angeles Co., in the drift of San Francisqueto Pass. In *Canada*, at Burgess, Ontario, red and blue crystals.

HEMATITE. Eisenglanz, *Germ.*

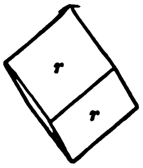
Rhombohedral. Axis $\dot{c} = 1{\cdot}3656$.

cr, $0001 \wedge 10\bar{1}1 = 57° 37'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 94° 0'$.
dd', $01\bar{1}2 \wedge \bar{1}012 = 64° 51'$.
uu', $10\bar{1}4 \wedge \bar{1}104 = 37° 2'$.
nn', $2\bar{2}43 \wedge \bar{2}4\bar{2}3 = 51° 59'$.
cn, $0001 \wedge 2\bar{2}43 = 61° 13'$.

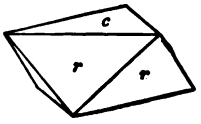
656.



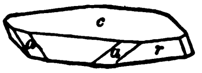
657.



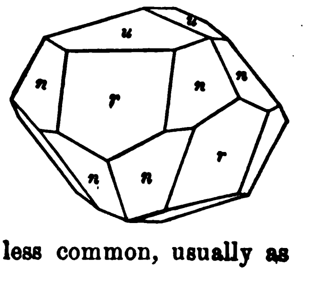
658.



659.



660.



Twins: tw. pl. (1) *c*, penetration-twins; (2) *r*, less common, usually as polysynthetic twinning lamellæ, producing a fine striation on *c*, and giving rise to a distinct parting or pseudo-cleavage ∥ *r*. Crystals often thick to thin tabular ∥ *c*, and grouped in parallel position or in rosettes; *c* faces striated ∥ edge *c*/*d* and other forms due to oscillatory combination; also in cube-like rhombohedrons; rhombohedral faces *u* (10$\bar{1}$4) horizontally striated and often rounded over in convex forms. Also columnar to granular, botryoidal, and stalactitic shapes; also lamellar, laminæ joined parallel to *c*, and variously bent, thick or thin; also granular, friable or compact.

Parting: *c*, due to lamellar structure; also *r*, caused by twinning. Fracture subconchoidal to uneven. Brittle in compact forms; elastic in thin laminæ; soft and unctuous in some loosely adherent scaly varieties. H. = 5·5–6·5. G. = 4·9–5·3; of crystals mostly 5·20–5·25; of some compact varieties, as low as 4·2. Luster metallic and occasionally splendent; sometimes dull. Color dark steel-gray or iron-black; in very thin particles blood-red by transmitted light; when earthy, red. Streak cherry-red or reddish brown. Opaque, except when in very thin laminæ.

Var. 1. *Specular*. Luster metallic, and crystals often splendent, whence the name *specular iron* (Glanzeisenerz *Germ.*). When the structure is foliated or micaceous, the ore is called *micaceous* hematite (Eisenglimmer *Germ.*); some of the micaceous varieties are soft and unctuous (Eisenrahm *Germ.*). Some varieties are magnetic, but probably from admixed magnetite (Arts. **424**, **426**).

2. *Compact columnar;* or fibrous. The masses often long radiating; luster submetallic to metallic; color brownish red to iron-black. Sometimes called *red hematite*, to contrast it with limonite and turgite. Often in reniform masses with smooth fracture, called *kidney ore*.

3. *Red Ocherous*. Red and earthy. *Reddle* and *red chalk* are red ocher, mixed with more or less clay.

4. *Clay Iron-stone; Argillaceous hematite*. Hard, brownish black to reddish brown, often in part deep red; of submetallic to unmetallic luster; and affording, like all the preceding, a red streak. It consists of oxide of iron with clay or sand, and sometimes other impurities.

Comp.—Iron sesquioxide, Fe_2O_3 = Oxygen 30, iron 70 = 100. Sometimes contains titanium and magnesium, and is thus closely related to ilmenite, p. 336.

Pyr., etc.—B.B. infusible; on charcoal in R.F. becomes magnetic; with borax gives the iron reactions. With soda on charcoal in R.F. is reduced to a gray magnetic metallic powder. Soluble in concentrated hydrochloric acid.

Diff.—Distinguished from magnetite by its *red streak*, also from limonite by the same means, as well as by its not containing water; from turgite by its greater hardness and by not decrepitating B.B. It is *hard* in all but some micaceous varieties (hence easily distinguished from the black sulphides); also *infusible*, and B.B. becomes strongly magnetic.

Obs.—This ore occurs in rocks of all ages. The specular variety is mostly confined to crystalline or metamorphic rocks, but is also a result of igneous action about some volcanoes, as at Vesuvius. Many of the geological formations contain the argillaceous variety or clay iron-stone, which is mostly a marsh-formation, or a deposit over the bottom of shallow, stagnant water; but this kind of clay iron-stone (that giving a red powder) is less common than the corresponding variety of limonite. The beds that occur in metamorphic rocks are sometimes of very great thickness, and, like those of magnetite in the same situation, have resulted from the alteration of stratified beds of ore, originally of marsh origin, which were formed at the same time with the enclosing rocks, and underwent metamorphism, or a change to the crystalline condition, at the same time.

Beautiful crystallizations of this species are brought from the island of Elba, which has afforded it from a very remote period; the surfaces of the crystals often present an irised tarnish and brilliant luster. St. Gothard affords beautiful specimens, composed of crystallized tables grouped in the form of rosettes (*Eisenrosen*); near Limoges, France, in large crystals; fine crystals are the result of volcanic action at Etna and Vesuvius. Arendal in Norway, Långban and Nordmark in Sweden, Framont in Lorraine, Dauphiné, Binnenthal and Tavetsch, Switzerland, also Cleator Moor in Cumberland, afford splendid specimens.

Red hematite occurs in reniform masses of a fibrous concentric structure, near Ulverstone in Lancashire, in Saxony, Bohemia, and the Harz.

In *N. America*, widely distributed, and sometimes in beds of vast thickness in rocks of the Archæan age, as in the upper peninsula of Michigan, in the Marquette district, also in Menominee county and west of Lake Agogebic in Gogebic county; further through northern Wisconsin, in Florence, Ashland and Dodge Cos., and in Minnesota near Vermilion lake, St. Louis Co.; in Missouri, at the Pilot Knob and the Iron Mtn.

In New York, in Oneida, Herkimer, Madison, Wayne Cos., a lenticular argillaceous var., constituting one or two beds in the Clinton group of the Upper Silurian; the same in Pennsylvania, and as far south as Alabama; and in Canada, and Wisconsin to the west; in Alabama there are extensive beds; prominent mines are near Birmingham. Besides these regions of enormous beds, there are numerous others of workable value, either crystallized or argillaceous. Some of these localities, interesting for their specimens, are in northern New York, at Gouverneur, Antwerp, Hermon, Edwards, Fowler, Canton, etc.; Woodstock and Aroostook, Me.; at Hawley, Mass., a micaceous variety; in North and South Carolina a micaceous variety in schistose rocks, constituting the so-called *specular schist*, or *itabirite*.

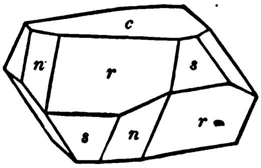
Named *hematite* from *αἷμα, blood.*

Martite. Iron sesquioxide under an isometric form, occurring in octahedrons or dodecahedrons like magnetite, and believed to be pseudomorphous after magnetite; perhaps in part also after pyrite. Parting octahedral like magnetite. Fracture conchoidal. H. = 6–7. G. = 4·8 (Brazil) to 5·3 (Monroe). Luster submetallic. Color iron-black, sometimes with a bronzed tarnish. Streak reddish brown or purplish brown. Not magnetic, or only feebly so. The crystals are sometimes embedded in the massive sesquioxide. They are distinguished from magnetite by the red streak, and very feeble, if any, action on the magnetic needle. Found in the Marquette iron region south of Lake Superior, where crystals are common in the ore; Monroe, N. Y.; Digby Co., N. S.; at the Cerro de Mercado, Durango, Mexico, in large octahedrons; in the schists of Minas Geraes, Brazil; near Rittersgrün, Saxony.

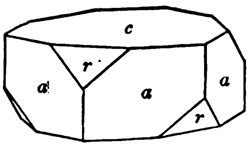
ILMENITE or **Menaccanite.** Titanic Iron Ore. Titaneisen *Germ.*

Tri-rhombohedral; Axis ċ = 1·3846.

661.



662.



cr, 0001 ∧ $10\bar{1}1$ = 57° 58½′.
rr′, $10\bar{1}1$ ∧ $\bar{1}101$ = 94° 29′.
cn, 0001 ∧ $22\bar{4}3$ = 61° 33′.

Crystals usually thick tabular; also acute rhombohedral. Often in thin plates or laminæ. Massive, compact; in embedded grains, also loose as sand.

Fracture conchoidal. H. = 5–6. G. = 4·5–5. Luster submetallic. Color iron-black. Streak submetallic, powder black to brownish red. Opaque. Influences slightly the magnetic needle.

Comp., Var.—If normal, $FeTiO_3$ or FeO,TiO_2 = Oxygen 31·6, titanium 31·6, iron 36·8 = 100. Sometimes written $(Fe,Ti)_2O_3$, but probably to be regarded as an iron titanate. Sometimes also contains magnesium (*picrotitanite*), replacing the ferrous iron; hence the general formula $(Fe,Mg)O.TiO_2$ (Penfield).

Pyr., etc.—B.B. infusible in O.F., although slightly rounded on the edges in R.F. With borax and salt of phosphorus reacts for iron in O.F., and with the latter flux assumes a more or less intense brownish-red color in R.F.; this treated with tin on charcoal changes to a violet-red color when the amount of titanium is not too small. The pulverized mineral, heated with hydrochloric acid, is slowly dissolved to a yellow solution, which, filtered from the undecomposed mineral and boiled with the addition of tin-foil, assumes a beautiful blue or violet color. Decomposed by fusion with bisulphate of sodium or potassium.

Diff.—Resembles hematite, but has a submetallic, nearly black, streak; not magnetic like magnetite.

Obs.—Occurs, as an accessory component, in many igneous rocks in grains, assuming the place of magnetite, especially in gabbros and diorites. In these occurrences, it is often found in veins or large segregated masses near the borders of the igneous rock where it is supposed to have formed by local differentiation or fractional crystallization in the molten mass. Some principal European localities are St. Cristophe, Dauphiné (var. *crichtonite*); Miask in the Ilmen Mts. (*ilmenite*); in the form of sand at Menaccan, Cornwall (*menaccanite*); Gastein in Tyrol (*kibdelophane*); Iserwiese (*iserine*). One of the most remarkable is at Kragerö, Norway, where it occurs in veins or beds in diorite, which sometimes afford crystals weighing over 16 pounds. Others are Egersund, Arendal, Snarum in Norway; St. Gothard, etc.

Fine crystals, sometimes an inch in diameter, occur in Warwick, Amity, and Monroe, Orange Co., N. Y.; Litchfield, Conn. (*washingtonite*). Vast deposits or beds of titanic ore occur at Bay St. Paul in Quebec, Canada, in syenite; also in the Seignory of St. Francis, Beauce Co. Grains are found in the gold sand of California.

The titanic iron of massive rocks is extensively altered to a dull white opaque substance, called *leucoxene* by Gümbel. This for the most part is to be identified with titanite.

Pyrophanite. Manganese titanate, $MnTiO_3$. In thin tabular rhombohedral crystals and scales, near ilmenite in form (p. 332). H. = 5. G. = 4·537. Luster vitreous to sub-metallic. Color deep blood-red. Streak ocher-yellow. From the Harstig mine, Pajsberg, Sweden.

III. Intermediate Oxides.

The species here included are retained among the oxides, although chemically considered they are properly oxygen-salts, aluminates, ferrates, manganates, etc., and hence in a strict classification to be placed in section 5. of the Oxygen-salts. The one well-characterized group is the Spinel Group.

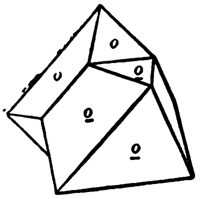
Spinel Group. $\overset{II}{R}\overset{III}{R}_2O_4$ or $\overset{II}{R}O.\overset{III}{R}_2O_3$. Isometric.

Spinel	$MgO.Al_2O_3$
Ceylonite	$(Mg,Fe)O.Al_2O_3$
Chlorospinel	$MgO.(Al,Fe)_2O_3$
Picotite	$(Mg,Fe)O.(Al,Cr)_2O_3$
Hercynite	$FeO.Al_2O_3$
Gahnite (Automolite)	$ZnO.Al_2O_3$
Dysluite	$(Zn,Fe,Mn)O.(Al,Fe)_2O_3$
Kreittonite	$(Zn,Fe,Mg)O.(Al,Fe)_2O_3$
Magnetite	$FeO.Fe_2O_3$
	$(Fe,Mg)O.Fe_2O_3$
Magnesioferrite	$MgO.Fe_2O_3$
Franklinite	$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$
Jacobsite	$(Mn,Mg)O.(Fe,Mn)_2O_3$
Chromite	$FeO.Cr_2O_3$
	$(Fe,Mg)O.(Cr,Fe)_2O_3$

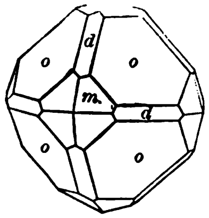
The species of Spinel Group are characterized by isometric crystallization, and, further, the octahedron is throughout the common form. All of the species are *hard;* those with unmetallic luster up to 7·5–8, the others from 5·5 to 6·5.

SPINEL.

663.



664.



Isometric. Usually in octahedrons, rarely cubic. Twins: tw.-pl. and comp.-face *o* common (Fig. 663), hence often called *spinel-twins;* also repeated and polysynthetic, producing tw. lamellæ.

Cleavage: *o* imperfect. Fracture conchoidal. Brittle. H. = 8. G. = 3·5–4·1. Luster vitreous; splendent to nearly dull. Color red of various shades, passing into blue, green, yellow, brown and black; occasionally almost white. Streak white. Transparent to nearly opaque. Refractive index: $n_y = 1·7155$ Na, Dx.

Comp., Var.—Magnesium aluminate, $MgAl_2O_4$ or $MgO.Al_2O_3$ = Alumina 71·8, magnesia 28·2 = 100. The magnesium may be in part replaced by ferrous iron or manganese, and the aluminium by ferric iron and chromium.

Var.—RUBY SPINEL or ***Magnesia Spinel.***—Clear red or reddish; transparent to translucent; sometimes subtranslucent. G. = 3·63–3·71. Composition normal, with little or no iron, and sometimes chromium oxide to which the red color has been ascribed. The varieties are: (*a*) *Spinel-Ruby*, deep red; (*b*) ***Balas-Ruby***, rose-red; (*c*) ***Rubicelle***, yellow or orange-red; (*d*) ***Almandine***, violet.

CEYLONITE or ***Pleonaste, Iron-Magnesia Spinel.***—Color dark green, brown to black, mostly opaque or nearly so; G. = 3·5–3·6. Contains iron replacing the magnesium and perhaps also the aluminium, hence the formula $(Mg,Fe)O.Al_2O_3$ or $(Mg,Fe)O.(Al,Fe)_2O_3$.

CHLOROSPINEL or ***Magnesia-Iron Spinel.***—Color grass-green, owing to the presence of copper; G. = 3·591–3·594. Contains iron replacing the aluminium, $MgO.(Al,Fe)_2O_3$.

PICOTITE or ***Chrome-Spinel.***—Contains chromium and also has the magnesium largely replaced by iron, $(Mg,Fe)O.(Al,Cr)_2O_3$, hence lying between spinel proper and chromite. G. = 4·08. Color dark yellowish brown or greenish brown. Translucent to nearly opaque.

Pyr, etc.—B.B. alone infusible. Slowly soluble in borax, more readily in salt of phosphorus, with which it gives a reddish bead while hot, becoming faint chrome-green on cooling. Black varieties give reactions for iron with the fluxes. Soluble with difficulty in concentrated sulphuric acid. Decomposed by fusion with potassium bisulphate.

Diff.—Distinguished by its octahedral form, hardness, and infusibility; zircon has a higher specific gravity; the true ruby (p. 333) is harder and is distinguished optically; garnet is softer and fusible.

Obs.—Spinel occurs embedded in granular limestone, and with calcite in serpentine, gneiss, and allied rocks. Ruby spinel is a common associate of the true ruby. Common spinel is often associated with chondrodite. It also occupies the cavities of masses ejected from some volcanoes. Spinel (common spinel, also picotite and chromite) occurs as an accessory constituent in many basic igneous rocks, especially those of the peridotite group; it is the result of the crystallization of a magma very low in silica, high in magnesia and containing alumina; since, as in many of the peridotites alkalies are absent, feldspars cannot form, and the Al_2O_3 and Cr_2O_3 (also Fe_2O_3 perhaps) are compelled to form spinel (or corundum). The serpentines which yield spinel are altered peridotites.

In Ceylon, in Siam, and other eastern countries, occurs of beautiful colors, as rolled pebbles; in upper Burma with the ruby (cf. p. 334). Pleonaste is found at Candy, in Ceylon; at Åker, in Sweden, a pale blue and pearl-gray variety in limestone; small black splendent crystals occur in the ancient ejected masses of Monte Somma; also at Pargas, Finland, with chondrodite, etc.; in compact gehlenite at Monzoni, in the Fassa valley.

From Amity, N. Y., to Andover, N. J., a distance of about 30 miles, is a region of granular limestone and serpentine, in which localities of spinel abound; colors, green, black, brown, and less commonly red, along with chondrodite and other minerals. Localities are numerous about Warwick, and also at Monroe and Cornwall; Gouverneur, 3 m. N. and ¾ m. W. of Somerville, St. Lawrence Co.; green, blue, and occasionally red varieties occur at Bolton, Boxborough, etc., Mass. Franklin, N. J., affords crystals of various shades of black, blue, green, and red; Newton, Sterling, Sparta, Hamburgh and Vernon, N. J., are other localities. With the corundum of North Carolina, as at the

Culsagee mine, near Franklin, Macon Co.; similarly at Dudleyville, Alabama. Spinel ruby at Gold Bluff, Humboldt Co., Cal.

Good black spinel is found in Burgess, Ontario; a bluish spinel having a rough cubic form occurs at Wakefield, Ottawa Co.; blue with clintonite at Daillebout, Joliette Co., Quebec.

Hercynite. Iron Spinel, $FeAl_2O_4$. Isometric; massive, fine granular. H. = 7·5–8. G. = 3·91–3·95. Color black. From Ronsberg, at the eastern foot of the Böhmerwald. A related iron-alumina spinel, with about 9 p. c. MgO, occurs with magnetite and corundum in Cortlandt township, Westchester Co., N. Y.

GAHNITE. Zinc-Spinel.

Isometric. Habit octahedral, often witn faces striated ‖ edge *d*/*o*; also less commonly in dodecahedrons and modified cubes. Twins: tw.-pl. *o*.

Cleavage: *o* indistinct. Fracture conchoidal to uneven. Brittle. H. = 7·5–8. G. = 4·0–4·6. Luster vitreous, or somewhat greasy. Color dark green, grayish green, deep leek-green, greenish black, bluish black, yellowish, or grayish brown; streak grayish. Subtransparent to nearly opaque.

Comp., Var.—Zinc aluminate, $ZnAl_2O_4$ = Alumina 55·7, zinc oxide 44·3 = 100. The zinc is sometimes replaced by manganese or ferrous iron, the aluminium by ferric iron.

Var.—AUTOMOLITE, or *Zinc Gahnite.*—$ZnAl_2O_4$, with sometimes a little iron. G. = 4·1–4·6. Colors as above given.

DYSLUITE, or *Zinc-Manganese-Iron Gahnite.*—$(Zn,Fe,Mn)O.(Al,Fe)_2O_3$. Color yellowish brown or grayish brown. G. = 4–4·6.

KREITTONITE, or *Zinc-Iron Gahnite.*—$(ZnFe,Mg)O.(Al,Fe)_2O_3$. In crystals, and granular massive. H. = 7–8. G. = 4·48–4·89. Color velvet-black to greenish black; powder grayish green. Opaque.

Pyr., etc.—Gives a coating of zinc oxide when treated with a mixture of borax and soda on charcoal; otherwise like spinel.

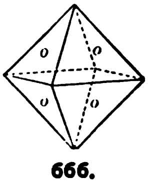
Obs.—Occurs in talcose schist at Falun, Sweden (*automolite*); at Tiriola, Calabria; at Bodenmais, Bavaria (*kreittonite*); Minas Geraes, Brazil. In the U. S., at Franklin Furnace, N. J., with franklinite and willemite; also at Sterling Hill, N. J. (*dysluite*); with pyrite at Rowe, Mass.; at a feldspar quarry in Delaware Co., Penn.; sparingly at the Deake mica mine, Mitchell Co., N. C.; at the Canton Mine, Georgia; with galena, chalcopyrite, pyrite at the Cotopaxi mine, Chaffee Co., Colo.

Named after the Swedish chemist Gahn. The name *Automolite*, of Ekeberg, is from *αὐτόμολος, a deserter*, alluding to the fact of the zinc occurring in an unexpected place.

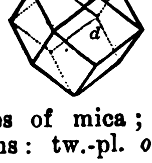
MAGNETITE. Magnetic Iron Ore. Magneteisenstein, Magneteisenerz.

Isometric. Most commonly in octahedrons, also in dodecahedrons with faces striated ‖ edge *d*/*o* from oscillatory combination; in dendrites between plates of mica; crystals sometimes highly modified; cubic forms rare. Twins: tw.-pl. *o*, sometimes as polysynthetic twinning lamellæ, producing

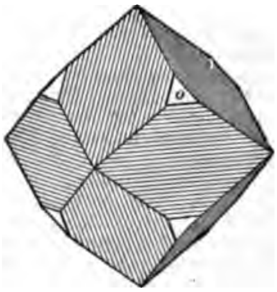
665.



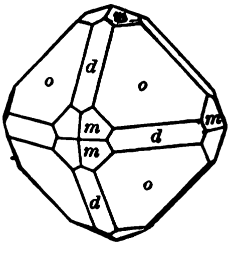
666.



667.



668.



striations on an octahedral face and often a pseudo-cleavage (Fig. 456, p. 136). Massive with laminated structure; granular, coarse or fine; impalpable.

Cleavage not distinct; parting octahedral, often highly developed. Fracture subconchoidal to uneven. Brittle. H. = 5·5–6·5. G. = 5·168–5·180 crystals. Luster metallic and splendent to submetallic and rather dull. Color iron-black. Streak black. Opaque, but in thin dendrites in mica nearly transparent and pale brown to black. Strongly magnetic; sometimes possessing polarity (lodestone).

Comp., Var.—$\overset{\text{II}}{\text{Fe}}\overset{\text{III}}{\text{Fe}}_2\text{O}_4$ or $\text{FeO.Fe}_2\text{O}_3$ = Iron sesquioxide 69·0, iron protoxide 31·0 = 100; or, Oxygen 27·6, iron 72·4 = 100. The ferrous iron sometimes replaced by magnesium, and rarely nickel; also sometimes contains titanium (up to 6 p. c. TiO_2).

Var.—*Ordinary.*—(*a*) In crystals. (*b*) Massive, with pseudo-cleavage, also granular, coarse or fine. (*c*) As loose sand. (*d*) Ocherous: a black earthy kind. Ordinary magnetite is attracted by a magnet but has no power of attracting particles of iron itself. The property of polarity which distinguishes the *lodestone* (less properly written loadstone) is exceptional.

Magnesian. Talk-Eisenerz.—G. = 4·41–4·42; luster submetallic; weak magnetic; in crystals from Sparta, N. J., and elsewhere.

Manganesian.—Containing 3·8 to 6·3 p. c. manganese (*Manganmagnetite*). From Vester Silfberg, Sweden.

Pyr., etc.—B.B. very difficultly fusible. In O.F. loses its influence on the magnet. With the fluxes reacts like hematite. Soluble in hydrochloric acid.

Diff.—Distinguished from other members of the spinel group, as also from garnet, by its being attracted by the magnet, as well as by its high specific gravity; franklinite and chromite are only feebly magnetic (if at all), and have a brown or blackish-brown streak; also, when massive, by its black streak from hematite and limonite; much harder than tetrahedrite.

Obs.—Magnetite is mostly confined to crystalline rocks, and is most abundant in metamorphic rocks, though widely distributed also in grains in eruptive rocks. In the Archæan rocks the beds are of immense extent, and occur under the same conditions as those of hematite. It is an ingredient in most of the massive variety of corundum called emery. The earthy magnetite is found in bogs like bog-iron ore. Occurs in meteorites, and forms the crust of meteoric irons.

Present in dendrite-like forms in the mica of many localities following the direction of the lines of the percussion-figure, and perhaps of secondary origin. A common alteration-product of minerals containing iron protoxide, *e.g.*, present in veins in the serpentine resulting from altered chrysolite.

The beds of ore at Arendal, Norway, and nearly all the celebrated iron mines of Sweden, consist of massive magnetite, as at Dannemora and the Täberg in Småland. Falun, in Sweden, and Corsica, afford octahedral crystals, embedded in chlorite slate. Splendid dodecahedral crystals occur at Nordmark in Wermland. The most powerful native magnets are found in Siberia, and in the Harz; they are also obtained on the island of Elba. Other localities for the crystallized mineral are Traversella in Piedmont; Achmatovsk in the Ural; Scalotta, near Predazzo, in Tyrol, also Rothenkopf and Wildkreuzjoch; the Binnenthal, Switzerland.

In N. America, it constitutes vast beds in the Archæan, in the Adirondack region, Warren, Essex, and Clinton Cos., in Northern N. York, while in St. Lawrence Co. the iron ore is mainly hematite; fine crystals and masses showing broad parting surfaces and yielding large pseudo-crystals are obtained at Port Henry, Essex Co.; similarly in New Jersey; in Canada, in Hull, Grenville, Madoc, etc.; at Cornwall in Pennsylvania, and Magnet Cove, Arkansas. It occurs also in *N. York*, in Saratoga, Herkimer, Orange, and Putnam Cos.; at the Tilly Foster iron mine, Brewster, Putnam Co., in crystals and massive accompanied by chondrodite, etc. In *N. Jersey*, at Hamburg, near Franklin Furnace and elsewhere. In *Penn.*, at Goshen, Chester Co., and at the French Creek mines; delineations forming hexagonal figures in mica at Pennsbury. Good lodestones are obtained at Magnet Cove, Arkansas. In *California*, in Sierra Co., abundant, massive, and in crystals; in Plumas Co.; and elsewhere. In Washington, in large deposits

Named from the loc. *Magnesia*, bordering on Macedonia. But Pliny favors Nicander's derivation from Magnes, who first discovered it, as the fable runs, by finding, on taking his herds to pasture, that the nails of his shoes and the iron ferrule of his staff adhered to the ground.

FRANKLINITE.

Isometric. Habit octahedral; edges often rounded, and crystals passing into rounded grains. Massive, granular, coarse or fine to compact.

Pseudo-cleavage, or parting, octahedral, as in magnetite. Fracture conchoidal to uneven. Brittle. H. = 5·5–6·5. G. = 5·07–5·22. Luster metallic, sometimes dull. Color iron-black. Streak reddish brown or black. Opaque. Slightly magnetic.

Comp.—$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$, but varying rather widely in the relative quantities of the different metals present, while conforming to the general formula of the spinel group.

Pyr., etc.—B.B. infusible. With borax in O.F. gives a reddish amethystine bead (manganese), and in R.F. this becomes bottle-green (iron). With soda gives a bluish-green manganate, and on charcoal a faint coating of zinc oxide, which is much more marked when a mixture with borax and soda is used. Soluble in hydrochloric acid, sometimes with evolution of a small amount of chlorine.

Diff.—Resembles magnetite, but is only slightly attracted by the magnet, and has a dark brown streak; it also reacts for zinc on charcoal B.B.

Obs.—Occurs in cubic crystals near Eibach in Nassau; in amorphous masses at Altenberg, near Aix-la-Chapelle. Abundant at Mine Hill, Franklin Furnace, N. J., with willemite and zincite in granular limestone; also at Sterling Hill, two miles distant, associated with willemite.

Magnesioferrite. Magnoferrite. $MgFeO_4$. In octahedrons. H. = 6–6·5. G. = 4·568–4·654. Luster, color, and streak as in magnetite. Strongly magnetic. Formed about the fumaroles of Vesuvius, and especially those of the eruption of 1855.

Jacobsite. $(Mn,Mg)O.(Fe,Mn)_2O_3$. Isometric; in distorted octahedrons. H. = 6. G. = 4·75. Color deep black. Magnetic. From Jakobsberg, in Nordmark, Wermland, Sweden; also at Långban.

CHROMITE.

Isometric. In octahedrons. Commonly massive; fine granular to compact.

Fracture uneven. Brittle. H. = 5·5. G. = 4·32–4·57. Luster submetallic to metallic. Color between iron-black and brownish black, but sometimes yellowish red in very thin sections. Streak brown. Translucent to opaque. Sometimes feebly magnetic.

Comp.—$FeCr_2O_4$ or FeO,Cr_2O_3 = Chromium sesquioxide 68·0, iron protoxide 32·0 = 100.

The iron may be replaced by magnesium; also the chromium by aluminium and ferric iron. The varieties containing but little chromium (up to 10 p. c.) are hardly more than varieties of spinel and are classed under picotite, p. 338.

Pyr., etc.—B.B. in O.F. infusible; in R.F. slightly rounded on the edges, and becomes magnetic. With borax and salt of phosphorus gives beads which, while hot, show only a reaction for iron, but on cooling become chrome-green; the green color is heightened by fusion on charcoal with metallic tin. Not acted upon by acids, but decomposed by fusion with potassium or sodium bisulphate.

Diff.—Distinguished from magnetite by feebly magnetic properties, streak and by yielding the reaction for chromic acid with the blowpipe.

Obs.—Occurs in serpentine, forming veins, or in embedded masses. It assists in giving the variegated color to verde-antique marble. Not uncommon in meteoric irons, sometimes in nodules as in the Coahuila iron, less often in crystals (Lodran).

Occurs in the Gulsen mountains, near Kraubat in Styria; in crystals in the islands of Unst and Fetlar, in Shetland; in the province of Trondhjem in Norway; in the Department du Var in France; in Silesia and Bohemia; abundant in Asia Minor; in the Eastern and Western Urals; in New Caledonia, affording ore for commerce.

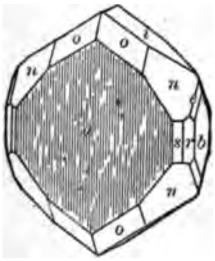
At Baltimore, Md., in the Bare Hills, in veins or masses in serpentine; also in Montgomery Co., etc. In Pennsylvania, Chester Co., near Unionville, abundant; at Wood's Mine, near Texas, Lancaster Co., very abundant. Massive and in crystals at Hoboken, N.

J., in serpentine and dolomite. In the southwestern part of the town of New Fane, etc., Vt. In California, in Monterey Co.; also Santa Clara Co., near the N. Almaden mine.

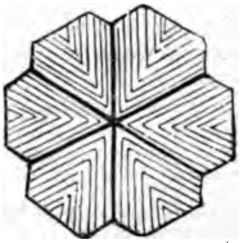
CHRYSOBERYL. Cymophane.

Orthorhombic. **Axes** $\breve{a} : \bar{b} : \dot{c}$ = 0·4701 : 1 : 0·5800.

669.



670.



mm‴,	110	∧	$1\bar{1}0$	=	50° 21′.
ss′,	120	∧	$\bar{1}20$	=	93° 32′.
xx′,	101	∧	$\bar{1}01$	=	101° 57′.
ii′,	011	∧	$0\bar{1}1$	=	60° 14′.
ρρ′,	031	∧	$0\bar{3}1$	=	120° 14′.
oo′,	111	∧	$\bar{1}11$	=	93° 44′.
oo‴,	111	∧	$1\bar{1}1$	=	40° 7′.
nn′,	121	∧	$\bar{1}21$	=	77° 43′.

Twins: tw. pl. *ρ* **(031), both contact- and penetration-twins;** often repeated and forming pseudo-hexagonal crystals with or without re-entrant angles (Fig. 357, p. 122). Crystals generally tabular ‖ *a*. Face *a* striated vertically, in twins a feather-like striation (Fig. 670).

Cleavage: *i* (011) quite distinct; *b* imperfect; *a* more so. Fracture uneven to conchoidal. Brittle. H. = 8·5. G. = 3·5–3·84. Luster vitreous. Color asparagus-green, grass-green, emerald-green, greenish white, and yellowish green; greenish brown; yellow; sometimes raspberry- or columbine-red by transmitted light. Streak uncolored. Transparent to translucent. Sometimes a bluish opalescence or chatoyancy, and asteriated. Pleochroic, vibrations ‖ 𝔟 (= $\bar{b}$) orange-yellow, 𝔠 (= $\dot{c}$) emerald-green, 𝔞 (= $\breve{a}$) columbine-red. Optically +. Ax. pl. ‖ *b*. Bx ⊥ *c*. *β* = 1·7484. 2E = 84° 43′.

Var. 1. *Ordinary.*—Color pale-green, being colored by iron; also yellow and transparent and then used as a gem.

2. *Alexandrite.*—Color emerald-green, but columbine-red by transmitted light; valued as a gem. G. = 3·644, mean of results. Supposed to be colored by chromium. Crystals often very large, and in twins, like Fig. 357, either six-sided or six-rayed.

3. *Cat's-eye.*—Color greenish and exhibiting a fine chatoyant effect; from Ceylon.

Comp.—Beryllium aluminate, $BeAl_2O_4$ or $BeO.Al_2O_3$ = Alumina 80·2, glucina 19·8 = 100.

Pyr., etc.—B.B. alone unaltered; with soda, the surface is merely rendered dull. With borax or salt of phosphorus fuses with great difficulty. With cobalt solution, the powdered mineral gives a bluish color. Not attacked by acids.

Diff.—Distinguished by its extreme hardness, greater than that of topaz: by its infusibility; also characterized by its tabular crystallization, in contrast with beryl.

Obs.—In Minas Geraes, Brazil, and also in Ceylon, in rolled pebbles; at Marschendorf in Moravia; in the Ural, 85 versts from Ekaterinburg, in mica slate with beryl and phenacite, the variety *alexandrite;* in the Orenburg district, S. Ural, yellow; in the Mourne Mts., Ireland.

In the U. S., at Haddam, Ct., in granite traversing gneiss, with tourmaline, garnet, beryl; at Greenfield, near Saratoga, N. Y., with tourmaline, garnet, and apatite; Norway, Me., in granite with garnet; also at Stoneham, with fibrolite, etc.

Chrysoberyl is from *χρυσος, golden, βήρυλλος, beryl. Cymophane*, from *κῦμα, wave,* and *φαίνω, appear*, alludes to a peculiar opalescence the crystals sometimes exhibit. *Alexandrite* is after the Czar of Russia, Alexander I.

Hausmannite. Mn_3O_4 or $MnO.M_2O_3$. In tetragonal octahedrons and twins (Fig. 376, p. 125); also granular massive, particles strongly coherent. H. = 5–5·5. G. = 4·856. Luster submetallic. Color brownish black. Streak chestnut-brown. Occurs near Ilmenau in Thuringia; Ilefeld in the Harz; Filipstad, Långban, Nordmark, in Sweden.

Minium. Mennige *Germ.* Pb_3O_4 or $2PbO\ PbO_2$. Pulverulent, as crystalline scales. G. = 4·6. Color vivid red, mixed with yellow; streak orange-yellow. Occurs at Bleialf in the Eifel; Badenweiler in Baden, etc.

Crednerite. $Cu_3Mn_4O_9$ or $3CuO.2Mn_2O_3$. Foliated crystalline. H. = 4·5. G. = 4·9–5·1. Luster metallic. Color iron-black to steel-gray. Streak black, brownish. From Friedrichsrode.

Pseudobrookite. Probably $Fe_4(TiO_4)_3$. Usually in minute orthorhombic crystals, tabular ∥ a and often prismatic ∥ $\breve{b}$. G. = 4·4–4·98. Color dark brown to black. Streak ocher-yellow. Found with hypersthene (szaboite) in cavities of the andesite of Aranyer Berg, Transylvania, and elsewhere; on recent lava (1872) from Vesuvius; at Havredal, Bamle, Norway, embedded in kjerulfine (wagnerite) altered to apatite.

BRAUNITE.

Tetragonal. Axis $\dot{c}$ = 0·9850. Commonly in octahedrons, nearly isometric in angle (pp' = 70° 7′). Also massive.

Cleavage: p perfect. Fracture uneven to subconchoidal. Brittle. H. = 6–6·5. G. = 4·75–4·82. Luster submetallic. Color dark brownish black to steel-gray. Streak same.

Comp.—$3Mn_2O_3.MnSiO_3$ = Silica 10·0, manganese protoxide 11·7, manganese sesquioxide 78·3 = 100.

Pyr., etc.—B.B. infusible. With borax and salt of phosphorus gives an amethystine bead in O.F., becoming colorless in R.F. With soda gives a bluish-green bead. Dissolves in hydrochloric acid evolving chlorine, and leaving a residue of gelatinous or flocculent silica (Rg.). Marceline gelatinizes with acids

Obs.—Occurs in veins traversing porphyry, at Oehrenstock, near Ilmenau; near Ilefeld in the Harz; St. Marcel in Piedmont; at Elba; at Botnedal, Upper Tellemark, in Norway; at the manganese mines of Jakobsberg, Sweden, also at Långban, and at the Sjö mine, Grythyttan, Örebro. ***Marceline*** (heterocline) from St. Marcel, Piedmont, is impure braunite.

Bixbyite. Essentially $FeO.MnO_2$. In black isometric crystals. H. = 6–6.5. G. = 4·945. Occurs with topaz in cavities in rhyolite; from Utah.

IV. Dioxides, RO_2.

Rutile Group. Tetragonal.

		$\dot{c}$			$\dot{c}$
Cassiterite	SnO_2	0·6723	**Rutile**	TiO_2	0·6442
Polianite	MnO_2	0·6647	**Plattnerite**	PbO_2	0·6764

The RUTILE GROUP includes the dioxides of the elements tin, manganese, titanium, and lead. These compounds crystallize in the tetragonal system with closely similar angles and axial ratio; furthermore in habit and method of twinning there is much similarity between the two best known species included here.

With the Rutile Group is also sometimes included Zircon, $ZrO_2.SiO_2$; $\dot{c}$ = 0·6404. In this work, however, Zircon is classed among the silicates, with the allied species Thorite, $ThO_2.SiO_2$, $\dot{c}$ = 0·6402.

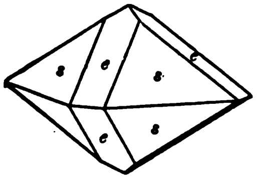
A tetragonal form, approximating closely to that of the species of the Rutile Group, belongs also to a number of other species, as Sellaite, MgF_2; Tapiolite, $Fe(Ta,Nb)_2O_6$; Xenotime, YPO_4, etc.

It may be added that ZrO_2, as the species Baddeleyite, crystallizes in the monoclinic system.

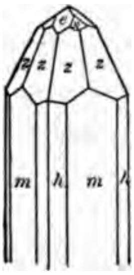
CASSITERITE. Tin-stone, Tin Ore. Zinnstein *Germ.*

Tetragonal. Axis $\dot{c} = 0{\cdot}6723$.

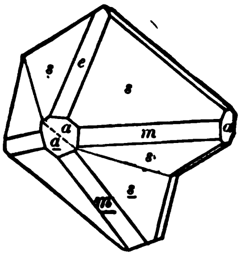
671.



672.



673.



ee', $101 \wedge 011 = 46^\circ\ 28'$.
ee'', $101 \wedge 101 = 67^\circ\ 50'$.
ss', $111 \wedge \bar{1}11 = 58^\circ\ 19'$.
ss'', $111 \wedge \bar{1}\bar{1}1 = 87^\circ\ 7'$.

ms, $110 \wedge 111 = 46^\circ\ 27'$.
zz', $321 \wedge 231 = 20^\circ\ 58\tfrac{1}{2}'$.
zz^{vii}, $321 \wedge 3\bar{2}1 = 61^\circ\ 42'$.

Twins common: tw. pl. *e*, both contact- and penetration-twins (Fig. 673, also Fig. 373, p. 124); often repeated. Crystals low pyramidal; also prismatic and acutely terminated. Often in reniform shapes, structure fibrous divergent; also massive, granular or impalpable; in rolled grains.

Cleavage: *a* imperfect; *s* (111) more so; *m* hardly distinct. Fracture subconchoidal to uneven. Brittle. H. = 6–7. G. = 6·8–7·1. Luster adamantine, and crystals usually splendent. Color brown or black; sometimes red, gray, white, or yellow. Streak white, grayish, brownish. Nearly transparent to opaque. Optically +. Indices: $\omega_y = 1{\cdot}9966$, $\epsilon_y = 2{\cdot}0934$.

Var.—*Ordinary.* Tin-stone. In crystals and massive.

Wood-tin (Holzzinnerz *Germ.*). In botryoidal and reniform shapes, concentric in structure, and radiated fibrous internally, although very compact, with the color brownish, of mixed shades, looking somewhat like dry wood in its colors. *Toad's-eye tin* is the same, on a smaller scale. *Stream tin* is the ore in the state of sand, as it occurs along the beds of streams or in gravel.

Comp.—Tin dioxide, SnO_2 = Oxygen 21·4, tin 78·6 = 100. A little Ta_2O_5 is sometimes present, also Fe_2O_3.

Pyr., etc.—B.B. alone unaltered. On charcoal with soda reduced to metallic tin, and gives a white coating. With the fluxes sometimes gives reactions for iron and manganese. Only slightly acted upon by acids.

Diff.—Distinguished by its high specific gravity, hardness, infusibility, and by its yielding metallic tin B.B.; resembles some varieties of garnet, sphalerite, and black tourmaline. Specific gravity (6·5) higher than that of rutile (4); wolframite is easily fusible.

Obs.—Occurs in veins traversing granite, gneiss, mica schist, chlorite or clay schist, and porphyry; also in finely reticulated veins forming the ore-deposits called stockworks, or simply impregnating the enclosing rock. The commonly associated minerals are quartz, wolframite, scheelite; also mica, topaz, tourmaline, apatite, fluorite; further pyrite, arsenopyrite, sphalerite; molybdenite, native bismuth, etc.

Formerly very abundant, now less so, in Cornwall, in fine crystals, and also as *wood-tin* and *stream-tin*; in Devonshire, near Tavistock and elsewhere; in pseudomorphs after feldspar at Wheal Coates, near St. Agnes, Cornwall; in fine crystals, often twins, at Schlackenwald, Graupen, Joachimsthal, etc., in Bohemia, and at Zinnwald, Ehrenfriedersdorf, Altenberg, etc., in Saxony; at Limoges in splendid crystals; Sweden, at Finbo; Finland, at Pitkäranta.

In the E. Indies, on the Malay peninsula of Malacca and the neighboring islands, Banca, and Bilitong near Borneo. In New South Wales abundant over an area of 8500 sq. miles, also in Victoria, Queensland and Tasmania. In Bolivia; Mexico, in Durango; also Guanajuato, Zacatecas, Jalisco.

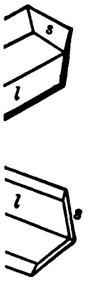
In the United States, in *Maine*, sparingly at Paris, Hebron, etc. In *Mass.*, at Chesterfield and Goshen, rare. In *N. Hamp.*, at Jackson. In *Virginia*, on Irish Creek, Rockbridge Co., with wolframite, etc. In *Alabama*, in Coosa Co. In *S. Dakota* near Harney Peak and near Custer City in the Black Hills, where it has been mined. In *Wyoming*, in Crook Co. In *Montana*, near Dillon. In *California*, in San Bernardino Co., at Temescal.

Polianite. Manganese dioxide, MnO_2. In composite parallel groupings of minute crystals; also forming the outer shell of crystals having the form of manganite. H. = 6–6·5. G. = 4·992. Luster metallic. Color light steel-gray or iron-gray. Streak black. From Platten, Bohemia. It is distinguished from pyrolusite by its hardness and its anhydrous character. Like pyrolusite it is often a pseudomorph after manganite.

RUTILE.

Tetragonal. Axis $\dot{c}$ = 0·64415.

5.



!'.

Test for tin. Grind the mineral in mortar & mix with sulphur & $NaCO_3$ in about equal proportion. Fuse in Porcelain crucible for 15 minutes or more with cover, so ~~that the S~~ does not burn. Dissolve fused mass in hot water & add HCl. a brown precipitate should form.

[illegible]

;act-twins of
p. 122; Fig.
5). Crystals
ler acicular.

onchoidal to
ster metallic-
es yellowish,
t deep red.
ctive indices
Sometimes

1 60·0 = 100.

–4·25. Trans-
illary crystals.
Fr. (or Venus
ular crystals of
hematite; also somewhat similarly on magnetite.

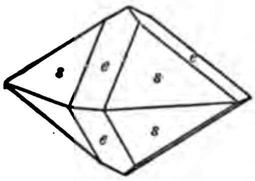
Ferriferous. (*a*) *Nigrine* is black in color, whence the name; contains 2 to 3 p. c. of Fe_2O_3 (*b*) *Ilmenorutile* is a black variety from the Ilmen Mts., containing up to 10 p. c. or more of Fe_2O_3. G. = 5·07 – 5·13.

Pyr., etc.—B.B. infusible. With salt of phosphorus gives a colorless bead, which in R.F. assumes a violet color on cooling. Most varieties contain iron, and give a brownish-yellow or red bead in R.F., the violet only appearing after treatment of the bead with metallic tin on charcoal. Insoluble in acids; made soluble by fusion with an alkali or

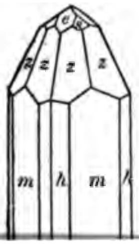
CASSITERITE. Tin-stone, Tin Ore. Zinnstein *Germ.*

Tetragonal. Axis $\dot{c}$ = 0·6723.

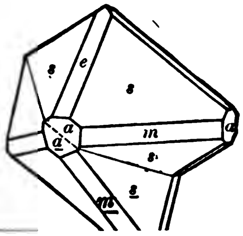
671.



672.



673.



ea
ea
ss
ss

Twins con
also Fig. 373,
and acutely te
also massive, g
Cleavage:
subconchoidal
mantine, and
red, gray, whi
parent to opaq

Var.—*Ordin*
Wood-tin (H
ture, and radiat
mixed shades, lo
a smaller scale.
streams or in gr

Comp.—Ti
is sometimes p

Pyr., etc.—I
gives a white co
Only slightly act

Diff.—Distin
ing metallic tin
Specific gravity (

Obs.—Occurs
porphyry; also i
simply impregna
wolframite, sche
pyrite, sphalerite

Formerly ver
and *stream-tin ;* in [illegible] and elsewhere, in pseudomorphs after
feldspar at Wheal Co[illegible]nes, Cornwall; in fine crystals, often twins, at
Schlackenwald, Graup[illegible]etc., in Bohemia, and at Zinnwald, Ehrenfriedersdorf, Altenberg, etc., in[illegible]es in splendid crystals; Sweden, at Finbo; Finland,
at Pitkäranta.

In the E. Indies, [illegible]ula of Malacca and the neighboring islands, Banca,
and Bilitong near B[illegible]h Wales abundant over an area of 8500 sq. miles,
also in Victoria, [illegible]ania. In Bolivia; Mexico, in Durango; also
Guanajuato, Z[illegible]

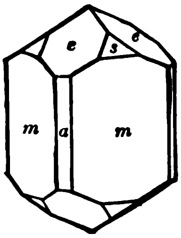
In the United States, in *Maine*, sparingly at Paris, Hebron, etc. In *Mass.*, at Chesterfield and Goshen, rare. In *N. Hamp.*, at Jackson. In *Virginia*, on Irish Creek, Rockbridge Co., with wolframite, etc. In *Alabama*, in Coosa Co. In *S. Dakota* near Harney Peak and near Custer City in the Black Hills, where it has been mined. In *Wyoming*, in Crook Co. In *Montana*, near Dillon. In *California*, in San Bernardino Co., at Temescal.

Polianite. Manganese dioxide, MnO_2. In composite parallel groupings of minute crystals; also forming the outer shell of crystals having the form of manganite. H. = 6–6·5. G. = 4·992. Luster metallic. Color light steel-gray or iron-gray. Streak black. From Platten, Bohemia. It is distinguished from pyrolusite by its hardness and its anhydrous character. Like pyrolusite it is often a pseudomorph after manganite.

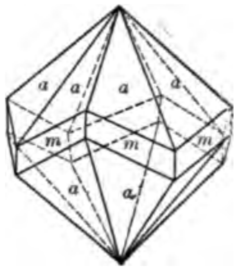
RUTILE.

Tetragonal. Axis $\dot{c}$ = 0·64415.

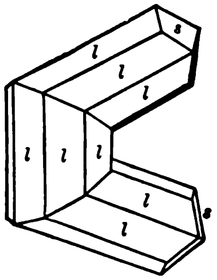
674.



675.



676.



ll^{vii}, 310 ∧ 310 = 36° 54′.
ee′, 101 ∧ 011 = 45° 2′.
ee″, 101 ∧ $\bar{1}01$ = 65° 34½′.

ss′, 111 ∧ $\bar{1}11$ = 56° 52½′.
ss″, 111 ∧ $\bar{1}\bar{1}1$ = 84° 40′.
tt′, 313 ∧ 133 = 29° 6′.

Twins: tw. pl. (1) *e*, often geniculated (Fig. 676); also contact-twins of very varied habit, sometimes sixlings and eightlings (Fig. 361, p. 122; Fig. 375, p. 124). (2) *v* (301) rare, contact-twins (Fig. 377, p. 125). Crystals commonly prismatic, vertically striated or furrowed; often slender acicular. Occasionally compact, massive.

Cleavage: *a* and *m* distinct; *s* in traces. Fracture subconchoidal to uneven. Brittle. H. = 6–6·5. G. = 4·18–4·25; also to 5·2. Luster metallic-adamantine. Color reddish brown, passing into red; sometimes yellowish, bluish, violet, black, rarely grass-green; by transmitted light deep red. Streak pale brown. Transparent to opaque. Optically +. Refractive indices high: $\omega_y = 2·6158$, $\epsilon_y = 2·9029$ for Na. Birefringence very high. Sometimes abnormally biaxial.

Comp., Var.—Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100. A little iron is usually present, sometimes up to 10 p. c.

Var.—*Ordinary.* Brownish red and other shades, not black. G. = 4·18–4·25. Transparent quartz (*sagenite*) is sometimes penetrated thickly with acicular or capillary crystals. Dark smoky quartz penetrated with the acicular rutile is the Flèches d'amour *Fr.* (or Venus hair-stone). Acicular crystals often implanted in parallel position on tabular crystals of hematite; also somewhat similarly on magnetite.

Ferriferous. (*a*) *Nigrine* is black in color, whence the name; contains 2 to 3 p. c. of Fe_2O_3 (*b*) *Ilmenorutile* is a black variety from the Ilmen Mts., containing up to 10 p. c. or more of Fe_2O_3. G. = 5·07 – 5·13

Pyr., etc.—B.B. infusible. With salt of phosphorus gives a colorless bead, which in R.F. assumes a violet color on cooling. Most varieties contain iron, and give a brownish-yellow or red bead in R.F., the violet only appearing after treatment of the bead with metallic tin on charcoal. Insoluble in acids; made soluble by fusion with an alkali or alkaline carbonate. The solution containing an excess of acid, with the addition of tin-foil, gives a beautiful violet color when concentrated.

Diff.—Characterized by its peculiar sub-adamantine luster and brownish-red color. Differs from tourmaline, vesuvianite, augite in being entirely unaltered when heated alone B.B. Specific gravity about 4, of cassiterite 6·5.

Obs.—Rutile occurs in granite, gneiss, mica slate, and syenitic rocks, and sometimes in granular limestone and dolomite; common, as a secondary product, in the form of microlites in many slates. It is generally found in embedded crystals, often in masses of quartz or feldspar, and frequently in acicular crystals penetrating quartz; also in phlogopite (wh. see), and has been observed in diamond. It has also been met with in hematite and ilmenite, rarely in chromite. It is common in grains or fragments in many auriferous sands.

Prominent localities are: Arendal and Kragerö in Norway; Horrsjöberg, Finland, with lazulite and cyanite; Saualpe, Carinthia; in the Urals; in Tyrol; at St. Gothard and Binnenthal, Switzerland; at Yrieux, near Limoges in France; at Ohlapian in Transylvania, *nigrine* in pebbles; in large crystals in Perthshire, Scotland; in Donegal Co., Ireland.

In *Maine*, at Warren. In *Vermont*, at Waterbury; also in loose bowlders in middle and northern Vermont, acicular, some specimens of great beauty in transparent quartz. In *Mass.*, at Barre, in gneiss; at Shelburne, in mica slate. In *N. York*, in Orange Co., Edenville; Warwick; E. of Amity. In *Penn.*, at Sudsbury, Chester Co., and the adjoining district in Lancaster Co.; at Parksburg, Concord, West Bradford, and Newlin, Chester Co.; at the Poor House quarry, Chester Co. In *N. Jersey*, at Newton, with spinel. In *N. Car.*, at Crowder's Mountain; at Stony Point, Alexander Co., in splendent crystals. In *Georgia*, in Habersham Co.; in Lincoln Co., at Graves' Mountain, with lazulite in large and splendent crystals. In *Arkansas*, at Magnet Cove, commonly in twins, with brookite and perovskite, also as paramorphs after brookite.

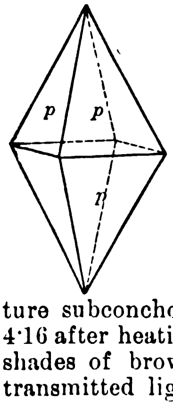
Plattnerite. Lead dioxide, PbO_2. Rarely in prismatic crystals, usually massive. H. = 5–5·5. G. = 8·5. Luster submetallic. Color iron-black. Streak chestnut-brown. From Leadhills and Wanlockhead, Scotland. Also at the "As You Like" mine, Mullan, Cœur d'Alêne Mts., Idaho.

Baddeleyite. Zircon dioxide, ZrO_2. In tabular monoclinic crystals. H. = 6·5. G. = 5·5–6·0. Colorless to yellow, brown and black. From Ceylon; also Jacupiranga, Brazil (*brazilite*) where it is associated with *zirkelite*, $(Ca,Fe)O.2(Zr,Ti,Th)O_2$.

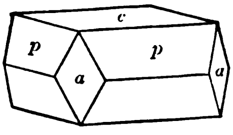
OCTAHEDRITE. Anatase.

Tetragonal. Axis $\dot{c} = 1·7771$.

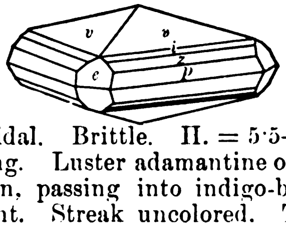
677.



678.



679.



Commonly octahedral in habit, either acute (*p*, 111), or obtuse (*v*, 117); also tabular, *c* predominating; rarely prismatic crystals; frequently highly modified.

ee', $101 \wedge 011 = 76° 5'$.
ee'', $101 \wedge \bar{1}01 = 121° 16'$.
pp', $111 \wedge \bar{1}11 = 82° 9'$.
pp'', $111 \wedge 1\bar{1}1 = 136° 36'$.
zz', $113 \wedge \bar{1}13 = 54° 1'$.
vv' $117 \wedge \bar{1}17 = 27° 39'$.

Cleavage: *c* and *p* perfect. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 3·82–3·95; sometimes 4·11–4·16 after heating. Luster adamantine or metallic-adamantine Color various shades of brown, passing into indigo-blue, and black; greenish yellow by transmitted light. Streak uncolored. Transparent to nearly opaque. Optically —. Birefringence rather high. Indices: $\omega_y = 2·554$, $\epsilon_y = 2·493$. Sometimes abnormally biaxial.

Comp.—Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100.

Pyr., etc.—Same as for rutile.

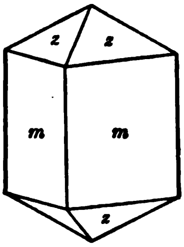
Obs.—Most abundant at Bourg d'Oisans, in Dauphiné, with feldspar, axinite, and ilmenite; near Hof in the Fichtelgebirge; Norway; the Urals; in chlorite in Devonshire, near Tavistock; with brookite at Tremadoc, in North Wales; in Cornwall, near Liskeard and at Tintagel Cliffs; in Brazil in quartz, and in detached crystals. In Switzerland in the Binnenthal the variety *wiserine*, long supposed to be xenotime; also Cavradi, Tavetsch; Rauris, Salzburg, in the Eastern Alps; also at Pfitsch Joch.

In the U. States, at the Dexter lime rock, Smithfield, R. I., in dolomite; in the washings at Brindletown, Burke Co., N. C., in transparent tabular crystals.

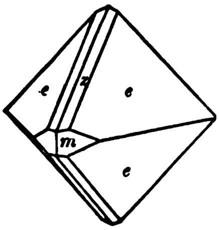
BROOKITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \acute{c} = 0{\cdot}8416 : 1 : 0{\cdot}9444$.

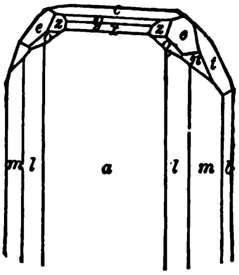
680.



681.



682.



mm''', $110 \wedge 1\bar{1}0 = 80° 10'$.
zz', $112 \wedge \bar{1}12 = 53° 48'$.
zz''', $112 \wedge 1\bar{1}2 = 44° 46'$.
ee', $122 \wedge \bar{1}22 = 44° 23'$.
ee''', $122 \wedge 1\bar{2}2 = 78° 57'$.
me, $110 \wedge 122 = 45° 42'$.

Only in crystals, of varied habit.

Cleavage: *m* indistinct; *c* still more so. Fracture subconchoidal to uneven. Brittle. H. = 5·5–6. G. = 3·87–4·08. Luster metallic-adamantine to submetallic. Color hair-brown, yellowish, reddish, reddish brown, and translucent; also brown to iron-black, opaque. Streak uncolored to grayish or yellowish. Optical characters, see p. 225.

Comp.—Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100.

Pyr.—Same as for rutile.

Obs.—Occurs at Bourg d'Oisans in Dauphiné; at St. Gothard, with albite and quartz; Maderaner Thal, Switzerland; in the Ural, district of Zlatoust, near Miask, and in the gold-washings in the Sanarka river and elsewhere; at Fronolen, near Tremadoc, Wales.

In the U. S., in thick black crystals (*arkansite*) at Magnet Cove, Ozark Mts., Arkansas, with elæolite, black garnet, schorlomite, rutile, etc.; in small crystals from the gold-washings of North Carolina; at the lead mine at Ellenville, Ulster Co., N. Y., on quartz, with chalcopyrite and galena; at Paris, Maine.

Named after the English mineralogist, H. J. Brooke (1771–1857).

PYROLUSITE.

Orthorhombic, but perhaps only pseudomorphous. Commonly columnar, often divergent; also granular massive, and frequently in reniform coats.

Soft, often soiling the fingers. H. = 2–2·5. G. = 4·73–4·86. Luster metallic. Color iron-black, dark steel-gray, sometimes bluish. Streak black or bluish black, sometimes submetallic. Opaque.

Comp.—Manganese dioxide. MnO_2, like polianite (p. 345). Commonly contains a little water (2 p. c.), it having had usually a pseudomorphous origin (after manganite).

It is uncertain whether pyrolusite is an independent species, with a crystalline form of its own, or only a secondary mineral derived chiefly from the dehydration of manganite; also from polianite (Breith.). Pseudomorphous crystals having distinctly the form of manganite are common.

Pyr., etc.—Like polianite, but most varieties yield some water in the closed tube.

Diff.—Hardness less than that of psilomelane. Differs from iron ores in its reaction for manganese B.B. Easily distinguished from psilomelane by its inferior hardness, and usually by being crystalline. Its streak is black; that of manganite is more or less brown.

Obs.—This ore is extensively worked at Elgersberg near Ilmenau, and other places in Thuringia; at Vorderehrensdorf in Moravia; at Platten in Bohemia, and elsewhere; near Johanngeorgenstadt; at Hirschberg in Westphalia; Matzka, Transylvania; in Australia; in India.

Occurs in the United States with psilomelane, abundantly in Vermont, at Brandon, etc.; at Plainfield and West Stockbridge, Mass.; Augusta Co., Virginia; Pope, Pulaski, Montgomery Cos., Arkansas. In New Brunswick, 7 m. fr. Bathurst. In Nova Scotia, at Teny Cape; at Walton, etc.

The name is from πῦρ, *fire*, and λούειν, *to wash*, because used to discharge the brown and green (FeO) tints of glass; and for the same reason it is whimsically entitled by the French *le savon de verriers*.

B. Hydrous Oxides.

Among the hydrous oxides the Diaspore Group is well characterized. Here belong the hydrates of aluminium, iron and manganese. The general formula is properly written $\overset{\text{III}}{R}O(OH)$. The three species here included are orthorhombic in crystallization with related angles and axial ratios; this relation is deviated from by manganite in the prismatic zone.

Another less prominent group is the Brucite Group, including the rhombohedral species Brucite, Mg(OH), and Pyrochroite, Mn(OH).

Gibbsite, $Al(OH)_3$, and Sassolite, $B(OH)_3$, are also related, and further Hydrotalcite and Pyroaurite.

Diaspore Group. $\overset{\text{III}}{R}O(OH)$ or $R_2O_3.H_2O$. Orthorhombic.

		$\breve{a} : \bar{b} : \acute{c}$	$\frac{c}{a}$
Diaspore	$Al_2O_3.H_2O$	0·9372 : 1 : 0·6039 or	0·6443
Göthite	$Fe_2O_3.H_2O$	0·9185 : 1 : 0·6068 or	0·6606
Manganite	$Mn_2O_3.H_2O$	0·8441 : 1 : 0·5448 or	0·6463

DIASPORE.

Orthorhombic. Axes: $\breve{a} : \bar{b} : \acute{c} = 0·9372 : 1 : 0·6039$. Crystals prismatic, $mm''' = 86° 17'$; usually thin, flattened ‖ *b*; sometimes acicular. Also foliated massive and in thin scales; sometimes stalactitic.

Cleavage: *b* eminent; *h* (210) less perfect. Fracture conchoidal, very brittle. H. = 6·5–7. G. = 3·3–3·5. Luster brilliant; pearly on cleavage-face, elsewhere vitreous. Color whitish, grayish white, greenish gray, hair-brown, yellowish, to colorless. Pleochroic. Transparent to subtranslucent. Optically +. Birefringence high. Ax. pl. ‖ *b*. Bx ⊥ *a*. Dispersion $\rho < v$, feeble. $2H_{a.y} = 103° 53'$. $\beta = 1·722$.

Comp.—AlO(OH) or $Al_2O_3.H_2O$ = Alumina 85·0, water 15·0 = 100.

Pyr., etc.—In the closed tube usually decrepitates strongly, separating into white pearly scales, and at a high temperature yields water. Infusible; with cobalt solution gives a deep blue color. Not attacked by acids, but after ignition soluble in sulphuric acid.

Diff.—Distinguished by its hardness and pearly luster; also (B.B.) by its decrepitation and yielding water; by the reaction for alumina with cobalt solution. Resembles some varieties of hornblende, but is harder.

Obs.—Commonly found with corundum or emery. Occurs near Kossoibrod, in the Ural; at Schemnitz, Hungary; with corundum in dolomite at Campolongo, Tessin, in

Switzerland: Greiner in the Zillerthal. In the U. S., with corundum and margarite at Newlin, Chester Co., Pa.; at the emery mines of Chester, Mass.; in cavities in massive corundum at the Culsagee mine, near Franklin, Macon Co., N. Carolina; with alunite forming rock masses at Mt. Robinson, Rosita Hills, Colorado.

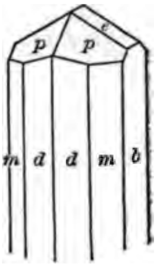
Named by Haüy from *διασπείρειν*, *to scatter*, alluding to the usual decrepitation before the blowpipe.

GÖTHITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·9185 : 1 : 0·6068.

mm''', $110 \wedge 1\bar{1}0 = 85° \; 8'$. *pp'*, $111 \wedge \bar{1}11 = 58° \; 55'$.
ee', $011 \wedge 0\bar{1}1 = 62° \; 30'$. *pp'''*, $111 \wedge 1\bar{1}1 = 53° \; 42'$.

683.



In prisms vertically striated, and often flattened into scales or tables ‖ *b*. Also fibrous; foliated or in scales; massive, reniform and stalactitic, with concentric and radiated structure.

Cleavage: *b* very perfect. Fracture uneven. Brittle. H. = 5–5·5. G. = 4·0–4·4. Luster imperfect adamantine. Color yellowish, reddish, and blackish brown. Often blood-red by transmitted light. Streak brownish yellow to ocher-yellow.

Var.—In thin scale-like or tabular crystals, usually attached by one edge. Also in acicular or capillary (not flexible) crystals, or slender prisms, often radiately grouped: the *Needle-Ironstone*. It passes into a variety with a velvety surface: the *Przibramite* (*Sammetblende*) of Přibram is of this kind. Also columnar, fibrous, etc., as above.

Comp.—FeO(OH) or $Fe_2O_3.H_2O$ = Oxygen 27·0, iron 62·9, water 10·1 = 100, or Iron sesquioxide 89·9, water 10·1 = 100.

Pyr., etc.—In the closed tube gives off water and is converted into red iron sesquioxide. With the fluxes like hematite; most varieties give a manganese reaction, and some, treated in the forceps in O.F., after moistening in sulphuric acid, impart a bluish-green color to the flame (phosphoric acid). Soluble in hydrochloric acid.

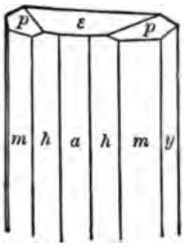
Diff.—Distinguished from hematite by its yellow streak; from limonite by crystalline nature; it also contains less water than limonite.

Obs.—Found with the other oxides of iron, especially hematite or limonite. Occurs at Eiserfeld near Siegen, in Nassau; at Clifton, near Bristol, England; in Cornwall. In the U. S., at the Jackson Iron mine, Negaunee, L. Superior; in Conn., at Salisbury; in Penn., near Easton; inothe Pike's Peak region, Colorado. Named *Göthite* (Goethite) after the poet-philosopher Goethe (1749–1832).

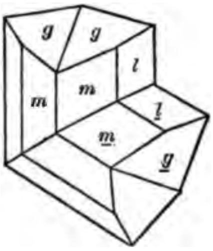
MANGANITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·8441 : 1 : 0·5448.

684.



685.



hh''', $410 \wedge 4\bar{1}0 = 23° \; 50'$.
mm''', $110 \wedge 1\bar{1}0 = 80° \; 20'$.
εε', $205 \wedge \bar{2}05 = 28° \; 57'$.
ee', $011 \wedge 0\bar{1}1 = 57° \; 10'$.
pp', $111 \wedge \bar{1}11 = 59° \; 5\tfrac{1}{2}'$.

Crystals commonly prismatic, the faces deeply striated vertically; often grouped in bundles. Twins: tw. pl. *e* (011). Also columnar; stalactitic.

Cleavage: *b* very perfect; *m* perfect. Fracture uneven. Brittle. H. = 4. G. = 4·2–4·4. Luster submetallic. Color dark steel-gray to iron-black. Streak reddish brown, sometimes nearlyblack. Opaque; in minute splinters sometimes brown by transmitted light.

Comp.—$MnO(OH)$ or $Mn_2O_3.H_2O$ = Oxygen 27·3, manganese 62·4, water 10·3 = 100, or Manganese sesquioxide 89·7, water 10·3 = 100.

Pyr., etc.—In the closed tube yields water; manganese reactions with the fluxes, p. 263.

Obs.—Occurs at Ilefeld in the Harz; Ilmenau in Thuringia; Cornwall, at various places; also in Cumberland, etc. In the L. Superior mining region at the Jackson mine, Negaunee; Devil's Head, Douglas Co., Colorado. In Nova Scotia, at Cheveric, Hants Co., and Walton. In New Brunswick, at Shepody mountain, Albert Co., etc.

LIMONITE. Brown Hematite. Brauneisenstein *Germ.*

Not crystallized. Usually in stalactitic and botryoidal or mammillary forms, having a fibrous or subfibrous structure; also concretionary, massive; and occasionally earthy.

H. = 5–5·5. G. = 3·6–4·0. Luster silky, often submetallic; sometimes dull and earthy. Color of surface of fracture various shades of brown, commonly dark, and none bright; sometimes with a nearly black varnish-like exterior; when earthy, brownish yellow, ocher-yellow. Streak yellowish brown. Opaque.

Var.—(1) *Compact.* Submetallic to silky in luster; often stalactitic, botryoidal, etc. (incl. brauner Glaskopf *Germ.*). (2) *Ocherous* or earthy, brownish yellow to ocher-yellow, often impure from the presence of clay, sand, etc. (3) *Bog ore.* The ore from marshy places, generally loose or porous in texture, often petrifying leaves, wood, nuts, etc. (4) *Brown clay-ironstone*, in compact masses, often in concretionary nodules.

Comp.—$2Fe_2O_3.3H_2O$ = Oxygen 25·7, iron 59·8, water 14·5 = 100, or Iron sesquioxide 85·5, water 14·5 = 100. In the bog ores and ochers, sand, clay, phosphates, oxides of manganese, and humic or other acids of organic origin are very common impurities.

Pyr., etc.—Like göthite. Some varieties leave a siliceous skeleton in the salt of phosphorus bead, and a siliceous residue when dissolved in acids.

Diff.—Distinguished from hematite by its yellowish streak, inferior hardness, and its reaction for water. Does not decrepitate B.B., like turgite. Not crystallized like göthite and yields more water.

Obs.—In all cases a result of the alteration of other ores, or minerals containing iron, through exposure to moisture, air, and carbonic or organic acids; derived largely from the change of pyrite, magnetite, siderite, ferriferous dolomite, etc.; also various species (as mica, pyroxene, hornblende, etc.), which contain iron in the ferrous state (FeO). It consequently occupies, as a bog ore, marshy places, into which it has been borne by streamlets from the hills around. It is often associated with manganese ores. Limonite is a common ore in Bavaria, the Harz, Luxembourg, Scotland, Sweden, etc.

Abundant in the United States. Extensive beds exist at Salisbury and Kent, Conn., also in the neighboring towns of New York, and in a similar situation in Berkshire Co., Mass., and in Vermont; in Pennsylvania widely distributed; also in Tennessee, Alabama, Ohio, etc.

Named *Limonite* from λειμών, *meadow.*

TURGITE. Hydrohematite. $Fe_4H_2O_7$ or $2Fe_2O_3.H_2O$. Resembles limonite but has a red streak. G. = 4·14–4·6. Decrepitates B.B. From the Turginsk mine in the Ural, etc.; also from Salisbury, Conn. Intermediate between hematite and limonite.

Xanthosiderite. Gelbeisenstein. $Fe_2O_3.2H_2O$. In fine needles or fibers, stellate and concentric; also as an ocher. Color golden yellowish, brown to brownish red. Associated with manganese ores at Ilmenau, etc.

BAUXITE. Beauxite.

In round concretionary disseminated grains. Also massive, oölitic; and earthy, clay-like. G. = 2·55. Color whitish, grayish, to ocher-yellow, brown, and red.

Var.—1. In concretionary grains, or oölitic; *bauxite*. 1 Clay-like, *wocheinite;* the purer kind grayish, clay-like, containing very little iron oxide; also red from the iron oxide present.

Comp.—Essentially $Al_2O_3.2H_2O$ = Alumina 73·9, water 26·1 = 100; some analyses, however, give $Al_2O_3.H_2O$ like diaspore.

Iron sesquioxide is usually present, sometimes in large amount, in part replacing alumina, in part only an impurity. Silica, phosphoric acid, carbonic acid, lime, magnesia are common impurities.

Obs.—From Baux (or Beaux), near Arles, and elsewhere in France, disseminated in grains in compact limestone, and also oölitic. *Wocheinite* occurs in Carniola, between Feistritz and Lake Wochein. The purest bauxite is used for the manufacture of aluminium (aluminum), and is called *aluminium ore*. In the U. S., bauxite occurs in Saline and Pulaski Cos., Arkansas; also in Cherokee and Calhoun Cos., Alabama, and in Floyd, Barton and Walker Cos., Georgia.

Brucite Group. $R(OH)_2$. Rhombohedral.

BRUCITE.

Rhombohedral. Axis $\dot{c}$ = 1·5208; cr = 60° 20½′, rr' = 97° 37½′.

Crystals usually broad tabular. Also commonly foliated massive; fibrous, fibers separable and elastic.

H. = 2·5. G. = 2·38–2·4. Cleavage: c eminent. Folia separable and flexible, nearly as in gypsum. Sectile. Luster ‖ c pearly, elsewhere waxy to vitreous. Color white, inclining to gray, blue, or green. Transparent to translucent. Optically +. Indices: $\omega_r = 1·559$, $\epsilon_r = 1·5795$.

Comp., Var.—Magnesium hydrate, $Mg(OH)_2$ or $MgO.H_2O$ = Magnesia 69·0, water 31·0 = 100. Iron and manganese protoxide are sometimes present.

Var.—*Ordinary*, occurring in plates, white to pale greenish in color; strong pearly luster on the cleavage surface. *Nemalite* is a fibrous variety containing 4 to 5 p. c. iron protoxide, with G. = 2·44 Nuttall. *Manganbrucite* contains manganese; occurs granular; color honey-yellow to brownish red.

Pyr., etc.—In the closed tube gives off water, becoming opaque and friable, sometimes turning gray to brown; the manganesian variety becomes dark brown. B.B. infusible, glows with a bright light, and the ignited mineral reacts alkaline to test-paper. With cobalt solution gives the pale pink color of magnesia. The pure mineral is soluble in acids without effervescence.

Diff.—Distinguished by its infusibility, softness, cleavage, and foliated structure. Is harder than talc and differs in its solubility in acids; the magnesia test and optical characters separate it from gypsum, which is also somewhat softer.

Obs.—Accompanies other magnesian minerals in serpentine, also found in limestone. At Swinaness in Unst, Shetland Isles; at the iron mine of Cogne, Aosta, Italy; near Filipstadt in Sweden. At Hoboken, N. J., in serpentine; at the Tilly Foster iron mine, Brewster, N. Y., well crystallized; Richmond Co., N. Y.; at Wood's mine, Texas, Pa., in large plates or masses, and often crystallizations several inches across; at Low's mine with hydromagnesite. *Nemalite*, the fibrous variety, occurs at Hoboken, and at Xettes in the Vosges. *Manganbrucite* occurs with hausmannite and other manganese minerals in the granular limestone of Jakobsberg, Nordmark, Sweden.

Named after the early American mineralogist, A. Bruce (1777–1818).

Pyrochroite. Manganese hydrate, $Mn(OH)_2$. Usually foliated, like brucite. Luster pearly. Color white, but growing dark on exposure. Occurs in magnetite at Pajsberg, Sweden; also at Nordmark; and at Franklin Furnace, N. J.

GIBBSITE. Hydrargillite.

Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c}$ = 1·7089 : 1 : 1·9184; β = 85° 29′. Crystals tabular ‖ c, hexagonal in aspect. Occasionally in spheroidal concretions. Also stalactitic, or small mammillary, incrusting, with smooth surface, and often a faint fibrous structure within.

Cleavage: c eminent. Tough. H. = 2·5–3·5. G. = 2·3–2·4. Color white, grayish, greenish, or reddish white. Luster of *c* pearly; of other faces vitreous; of surface of stalactites faint. Translucent; sometimes transparent in crystals. A strong argillaceous odor when breathed on.

Comp.—Aluminium hydrate, $Al(OH)_3$ or $Al_2O_3.3H_2O$ = Alumina 65·4, water 34·6 = 100.

Pyr., etc.—In the closed tube becomes white and opaque, and yields water. B.B. infusible, whitens, and does not impart a green color to the flame. With cobalt solution gives a deep blue color. Soluble in concentrated sulphuric acid.

Obs.—The crystallized gibbsite (hydrargillite) occurs in the Shishimsk mountains near Zlatoust in the Ural; also in crystals filling cavities in natrolite in the Langesundfiord, Norway; Ouro Preto, Minas Geraes, Brazil. In the U. S., in stalactitic form at Richmond, Mass., in a bed of limonite; at the Clove Mine, Union Vale, Dutchess Co., N. Y., on limonite; in Orange Co., N. Y.

Named after Col. George Gibbs.

Sassolite. Boric acid, $B(OH)_3$. Crystals tabular ∥ *c* (triclinic). Usually small white, pearly scales. G. = 1·48. From the waters of the Tuscan lagoons of Monte Rotondo and Castelnuovo. Exists also in other natural waters, as at Clear Lake, in Lake Co., California. Occurs also abundantly in the crater of Vulcano, Lipari isles.

Hydrotalcite. Perhaps $Al(OH)_3.3Mg(OH)_2.3H_2O$. Lamellar-massive, or foliated, somewhat fibrous. H. = 2. G. = 2·04–2·09. Color white. Luster pearly. Occurs at the mines of Shishimsk, district of Zlatoust, Ural; at Snarum, Norway, in serpentine (*hydrotalcite*).

Pyroaurite. Perhaps $Fe(OH)_3.3Mg(OH)_2.3H_2O$. Occurs at the Långban iron-mine, Wermland, Sweden, in gold-like submetallic scales (*pyroaurite*). In thin seams of a silvery white color in serpentine in the island Haaf-Grunay, Scotland (*igelströmite*).

Chalcophanite. Hydrofranklinite. $(Mn,Zn)O.2MnO_2.2H_2O$. In druses of minute tabular rhombohedral crystals; sometimes octahedral in aspect. Also in foliated aggregates; stalactitic and plumose. G. = 3·907. Luster metallic, brilliant. Color bluish black to iron-black. Streak chocolate-brown, dull. Occurs at Sterling Hill, near Ogdensburg, Sussex Co., N. J.

PSILOMELANE.

Massive and botryoidal; reniform; stalactitic. H. = 5–6. G. = 3·7–4·7. Luster submetallic, dull. Streak brownish black, shining. Color iron-black, passing into dark steel-gray. Opaque.

Comp.—A hydrous manganese manganate in which part of the manganese is often replaced by barium or potassium, perhaps conforming to H_4MnO_5. The material is generally very impure, and the composition hence doubtful.

Pyr., etc.—In the closed tube most varieties yield water, and all lose oxygen on ignition; with the fluxes reacts for manganese. Soluble in hydrochloric acid, with evolution of chlorine.

Obs.—A common but impure ore of manganese; frequently in alternating layers with pyrolusite. From Devonshire and Cornwall; Ilefeld in the Harz; also at Ilmenau, Siegen, etc. Forms mammillary masses at Brandon, etc., Vt. In Independence Co., and elsewhere in Arkansas. With pyrolusite at Douglas, Hants Co., Nova Scotia. Named from *ψιλός*, *smooth* or *naked*, and *μέλας*, *black*.

The following mineral substances here included are mixtures of various oxides, chiefly of manganese (MnO_2, also MnO), cobalt, copper, with also iron, and from 10 to 20 p. c. water. These are results of the decomposition of other ores—partly of oxides and sulphides, partly of manganesian carbonates, and can hardly be regarded as representing distinct mineral species.

WAD. In amorphous and reniform masses, either earthy or compact; also incrusting or as stains. Usually very soft, soiling the fingers; less often hard to H. = 6. G. = 3·0–4·26; often loosely aggregated, and feeling very light to the hand. Color dull black, bluish or brownish black.

BOG MANGANESE consists mainly of oxide of manganese and water, with some oxide of iron, and often silica, alumina, baryta

ASBOLITE, or *Earthy Cobalt*, contains oxide of cobalt, which sometimes amounts to 32 p. c.

LAMPADITE, or *Cupreous Manganese*, is a wad containing 4 to 18 p. c. of oxide of copper, and often oxide of cobalt also.

VI. Oxygen-salts.

The Sixth Class includes the salts of the various oxygen acids. These fall into the following seven sections: 1. Carbonates; 2. Silicates and Titanates; 3. Niobates and Tantalates; 4. Phosphates, Arsenates, etc.; also the Nitrates; 5. Borates and Uranates; 6. Sulphates, Chromates and Tellurates; 7. Tungstates and Molybdates.

1. CARBONATES.

A. Anhydrous Carbonates.

The Anhydrous Carbonates include two distinct isomorphous groups, the Calcite Group and the Aragonite Group. The metallic elements present in the former are calcium, magnesium, iron, manganese, zinc and cobalt; in the latter, they are calcium, barium, strontium and lead.

The species included are as follows:

Calcite Group. RCO_3. Rhombohedral.

			rr'	$\dot{c}$
Calcite	$CaCO_3$		74° 55′	0·8543
Dolomite	$(Ca,Mg)CO_3$	Tri-rhombohedral	73° 45′	0·8322
Normal Dolomite	$CaCO_3.MgCO_3$			
Ankerite	$CaCO_3.(Mg,Fe)CO_3$		73° 48′	0·8332
Magnesite	$MgCO_3$		72° 36′	0·8112
Breunnerite	$(Mg,Fe)CO_3$			
Mesitite	$2MgCO_3.FeCO_3$		72° 46′	0·8141
Pistomesite	$MgCO_3.FeCO_3$		72° 42′	0·8129
Siderite	$FeCO_3$		73° 0′	0·8184
Oligonite	$(Fe,Mn)CO_3$			
Rhodochrosite	$MnCO_3$		73° 0′	0·8184
Manganosiderite	$(Mn,Fe)CO_3$			
Manganocalcite pt.	$(Mn,Ca)CO_3$			
Smithsonite	$ZnCO_3$		72° 20′	0·8063
Monheimite	$(Zn,Fe)CO_3$			
Sphærocobaltite	$CoCO_3$			

This list gives not only the prominent species of this group, but also some of the isomorphous intermediate compounds.

The Calcite Group is characterized by rhombohedral crystallization. All the species show, when distinctly crystallized, perfect rhombohedral cleavage, the angle varying from 75° (and 105°) in calcite to 73° (and 107°) in siderite. This is exhibited in the table above.

2. Aragonite Group. RCO_3. Orthorhombic.

		mm'''	$\breve{a} : \bar{b} : \dot{c}$
Aragonite	$CaCO_3$	63° 48′	0·6224 : 1 : 0·7206
Bromlite	$(Ca,Ba)CO_3$		
Witherite	$BaCO_3$	62° 12′	0·6032 : 1 : 0·7302
Strontianite	$SrCO_3$	62° 41′	0·6090 : 1 : 0·7239
Cerussite	$PbCO_3$	62° 46′	0·6100 : 1 : 0·7230

The species of the **Aragonite Group** crystallize in the orthorhombic system, but the relation to those of the Calcite Group is made more close by the fact that the prismatic angle varies a few degrees only from 60° (and 120°) and the twinned forms with the fundamental prism as twinning-plane are pseudo-hexagonal in character.

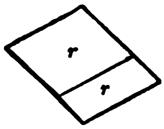
---

1. Calcite Group. RCO_3. Rhombohedral.

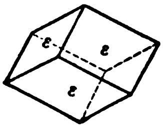
CALCITE. Kalkspath *Germ.* Calc Spar; Calcareous Spar.

Rhombohedral. Axis $\dot{c} = 0{\cdot}8543$.

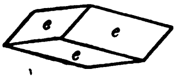
686.



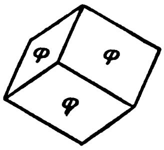
687.



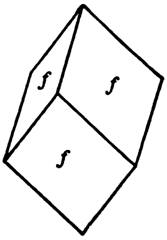
688.



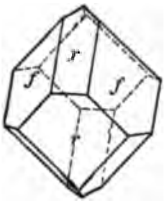
689.



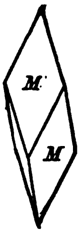
690.



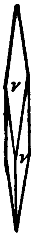
691.



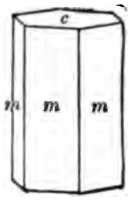
692.



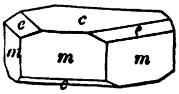
693.



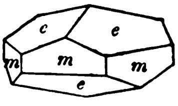
694.



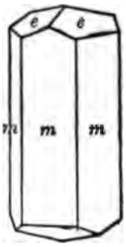
695.



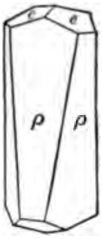
696.



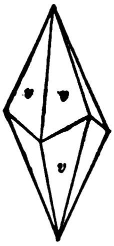
697.



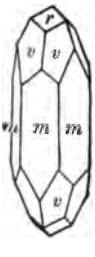
698.



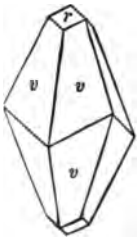
699.



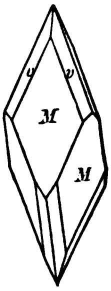
700.



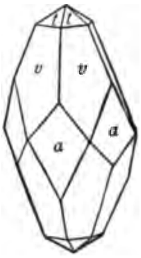
701.



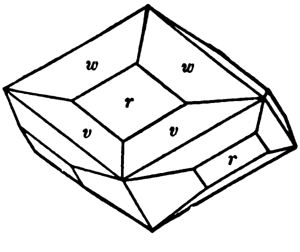
702.



703.



704.



cr,* $0001 \wedge 10\bar{1}1 = 44^\circ\ 36\tfrac{1}{2}'$.
ce, $0001 \wedge 01\bar{1}2 = 26^\circ\ 15'$.
me, $10\bar{1}0 \wedge 01\bar{1}2 = 63^\circ\ 45'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 74^\circ\ 55'$.
ee' $01\bar{1}2 \wedge \bar{1}012 = 45^\circ\ 3'$.
φφ', $05\bar{5}4 \wedge \bar{5}054 = 84^\circ\ 32\tfrac{1}{2}'$.
ff', $02\bar{2}1 \wedge \bar{2}021 = 101^\circ\ 9'$.
MM', $4041 \wedge \bar{4}401 = 114^\circ\ 10'$.

vv'. $21\bar{3}1 \wedge \bar{2}3\bar{1}1 = 75^\circ\ 22'$.
vv$^{\mathrm{v}}$, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35^\circ\ 36'$.
vv$^{\mathrm{vi}}$, $21\bar{3}1 \wedge 12\bar{3}\bar{1} = 47^\circ\ 1\tfrac{1}{2}'$.
yy', $32\bar{5}1 \wedge \bar{3}5\bar{2}1 = 70^\circ\ 59'$.
yy$^{\mathrm{v}}$, $32\bar{5}1 \wedge 5\bar{2}\bar{3}1 = 45^\circ\ 32'$.
yy$^{\mathrm{vi}}$, $32\bar{5}1 \wedge 23\bar{5}\bar{1} = 29^\circ\ 16'$.
tt$^{\mathrm{v}}$, $21\bar{3}4 \wedge 3\bar{1}\bar{2}4 = 20^\circ\ 36\tfrac{1}{2}'$.
ww$^{\mathrm{v}}$, $31\bar{4}5 \wedge 4\bar{1}\bar{3}5 = 16^\circ\ 0'$.

---

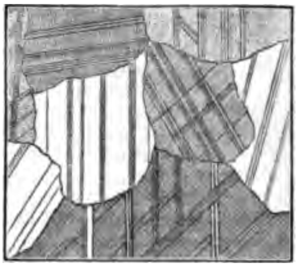
* See the spherical projection, Fig. 252, p. 79.

Habit of crystals very varied, as shown in the figures, from obtuse to acute rhombohedral; from thin tabular to long prismatic; and scalenohedral of many types, often highly modified.

Twins (see Figs. 383–390, p. 126): (1) Tw. pl. *c*, common, the crystals having the same vertical axis. (2) Tw. pl. *e* (01$\bar{1}$2), very common, the vertical axes inclined 127° 29½′ and 52° 30½′; often producing twinning lamellæ as in Iceland Spar, which are, in many cases of secondary origin as in granular limestones (Fig. 705); this twinning may be produced artificially (see p. 148). (3) Tw. pl. *r*, not common; the vertical axes inclined 90° 46′ and 89° 14′. (4) Tw. pl. *f* (02$\bar{2}$1), rare; the axes intersect at angles of 53° 46′ and 126° 14′.

Also fibrous, both coarse and fine; sometimes lamellar; often granular; from coarse to impalpable, and compact to earthy. Also stalactitic, tuberose, nodular, and other imitative forms.

705.



Section of crystalline limestone in polarized light.

Cleavage: *r* highly perfect. Parting ∥ *e* (01$\bar{1}$2) due to twinning. Fracture conchoidal, obtained with difficulty. H. = 3, but varying with the direction on the cleavage face; earthy kinds softer. G. = 2·714, in pure crystals, but varying somewhat widely in impure forms, as in those containing iron, manganese, etc. Luster vitreous to subvitreous to earthy. Color white or colorless; also various pale shades of gray, red, green, blue, violet, yellow; also brown and black when impure. Streak white or grayish. Transparent to opaque.

Optically —. Birefringence very high. Refractive indices for the D line: $\omega = 1{\cdot}65849$, $\epsilon = 1{\cdot}48625$.

Comp.—Calcium carbonate, $CaCO_3$ = Carbon dioxide 44·0, lime 56·0 = 100. Small quantities of magnesium, iron, manganese, zinc, and lead may be present replacing the calcium.

Var.—The varieties are very numerous, and diverse in appearance. They depend mainly on the following points: differences in crystallization and structural condition, presence of impurities, etc., the extremes being perfect crystals and earthy massive forms; also on composition as affected by isomorphous replacement.

A. Varieties based chiefly upon Crystallization and Accidental Impurities.

1. *Ordinary.* In crystals and cleavable masses, the crystals varying very widely in habit as already noted. *Dog-tooth Spar* is an acute scalenohedral form; *Nail-head Spar*, a composite variety having the form suggested by the name. The transparent variety from Iceland, used for polarizing prisms, etc., is called *Iceland Spar* or *Doubly-refracting Spar* (Doppelspath *Germ.*). As regards *color*, crystallized calcite varies from the kinds which are perfectly clear and colorless through yellow, pink, purple, blue, to brown and black. The color is usually pale except as caused by impurities. These impurities may be pyrite, native copper, malachite, sand, etc.; they are sometimes arranged in symmetrical form, as depending upon the growth of the crystals and hence produce many varieties.

Fontainebleau limestone, from Fontainebleau and Nemours, France, contains a large amount of sand, some 50 to 63 p. c. Similar forms occur at other localities.

2. *Fibrous and lamellar kinds.* *Satin Spar* is fine fibrous, with a silky luster; resembles fibrous gypsum, also called satin spar, but is much harder than gypsum and effervesces with acids.

Argentine is a pearly lamellar calcite, the lamellæ more or less undulating; color white, grayish, yellowish. *Aphrite*, in its harder and more sparry variety (*Schaumspath*), is a foliated white pearly calcite, near argentine; in its softer kinds (*Schaumerde*) it approaches chalk, though lighter, pearly in luster, silvery white or yellowish in color, soft and greasy to the touch, and more or less scaly in structure.

3. *Granular massive to cryptocrystalline kinds: Limestone, Marble, Chalk.*

Granular limestone or *Saccharoidal limestone*, so named because like loaf sugar in fracture, varying from coarse to very fine granular, and hence to *compact* limestone; colors are various, as white, yellow, reddish, green; usually they are clouded and give a handsome effect when the material is polished. When such limestones are fit for polishing, or for architectural or ornamental use, they are called *marbles*. Many varieties have special names. *Shell-marble* consists largely of fossil shells; *Lumachelle* or *fire-marble* is a dark brown shell-marble, with brilliant fire-like or chatoyant internal reflections. *Ruin-marble* is a kind of a yellow to brown color, showing, when polished, figures bearing some resemblance to fortifications, temples, etc., in ruins, due to infiltration of iron oxide, etc.

Lithographic stone is a very even-grained compact limestone, of buff or drab color; as that of Solenhofen. *Hydraulic limestone* is an impure limestone which after ignition sets, i.e., takes a solid form under water, due to the formation of a silicate. The French varieties contain 2 or 3 p. c. of magnesia, and 10 to 20 of silica and alumina (or clay). The varieties in the United States contain 20 to 40 p. c. of magnesia, and 12 to 30 p. c. of silica and alumina. *Hard compact limestone* varies from nearly pure white, through grayish, drab, buff, yellowish, and reddish shades, to bluish gray, dark brownish gray, and black, and sometimes variously veined. Many kinds make beautiful marble when polished. Red oxide of iron produces red of different shades. Shades of green are due to iron protoxide, chromium oxide, iron silicate.

Chalk is white, grayish white, or yellowish, and soft enough to leave a trace on a board. *Calcareous marl* is a soft earthy deposit, with or without distinct fragments of shells; it generally contains much clay, and graduates into a calcareous clay.

Oolite is a granular limestone, its grains minute concretions, looking somewhat like the roe of fish, the name coming from *ωόν*, *egg*. *Pisolite* (Erbsenstein) consists of concretions as large often as a small pea, or larger, having usually a distinct concentric structure.

Deposited from calcareous springs, streams, or in caverns, etc. (*a*) *Stalactites* are calcareous cylinders or cones that hang from the roofs of limestone caverns, and which are formed from the waters that drip through the roof; these waters hold some calcium bicarbonate in solution, and leave calcium carbonate to form the stalactite when evaporation takes place. Stalactites vary from transparent to nearly opaque; from a crystalline structure with single cleavage directions to coarse or fine granular cleavable and to radiating fibrous; from a white color and colorless to yellowish gray and brown. (*b*) *Stalagmite* is the same material covering the floors of caverns, it being made from the waters that drop from the roofs, or from sources over the bottom or sides; cones of it sometimes rise from the floor to meet the stalactites above. It consists of layers, irregularly curved, or bent. Stalagmite, or a solid kind of travertine (see below) when on a large scale, is the alabaster stone of ancient writers, that is, the stone of which ointment vases, of a certain form called *alabasters*, were made. A locality near Thebes, now well known, was largely explored by the ancients, and the material has often been hence called *Egyptian alabaster*. It was also formerly called *onyx* and *onychites* because of its beautiful banded structure. In the arts it is often now called *Oriental alabaster* or *onyx marble*. Very beautiful marble of this kind is obtained in Algeria. *Mexican onyx* is a similar material obtained from Tecali, Puebla, Mexico; also in a beautiful brecciated form from the extinct crater of Zempoaltepec in southern Mexico. Similar kinds occur in Missouri, Arizona, San Luis Obispo Co., California. (*c*) *Calc-sinter, Travertine, Calc Tufa.* Travertine is of essentially the same origin with stalagmite, but is distinctively a deposit from springs or rivers, especially where in large deposits, as along the river Anio, at Tivoli, near Rome, where the deposit is scores of feet in thickness. (*d*) *Agaric mineral;* Rock-milk is a very soft white material, breaking easily in the fingers, deposited sometimes in caverns, or about sources holding lime in solution. (*e*) *Rock-meal* is white and light, like cotton, becoming a powder on the slightest pressure.

B. VARIETIES BASED UPON COMPOSITION.

These include: *Dolomitic calcite*. Contains magnesium carbonate, thus graduating toward true dolomite. Also *baricalcite* (which contains some $BaCO_3$); similarly, *strontianocalcite* ($SrCO_3$), *ferrocalcite* ($FeCO_3$), *manganocalcite* ($MnCO_3$), *zincocalcite* ($ZnCO_3$), *plumbocalcite* ($PbCO_3$).

Pyr., etc.—B.B. infusible, but becomes caustic, glows, and colors the flame reddish yellow; after ignition the assay reacts alkaline; moistened with hydrochloric acid imparts the characteristic lime color to the flame. In the solid mass effervesces when moistened with hydrochloric acid, and fragments dissolve with brisk effervescence even in cold acid.

Diff.—Distinguishing characters: perfect rhombohedral cleavage; softness, can be scratched with a knife; effervescence in cold dilute acid; infusibility. Less hard and of lower specific gravity than aragonite (wh. see). Resembles in its different varieties the other rhombohedral carbonates, but is less hard, of lower specific gravity, and more readily attacked by acid. Also resembles some varieties of barite, but has lower specific gravity; it is less hard than feldspar and harder than gypsum.

Recognized in thin sections by its low refraction and very high birefringence, the polarization colors in the thinnest sections attaining white of the highest order. The negative interference figure, with many closely crowded colored rings, is also characteristic. The rhombohedral cleavage is often shown in the fine fracture lines; systems of twinned lamellæ often conspicuous (Fig. 705), especially in crystalline limestone.

Obs.—Calcite, in its various forms, is one of the most widely distributed of minerals. Beds of sedimentary limestone, formed from organic remains, shells, crinoids, corals, etc., yield on metamorphism crystalline limestone or marble, and in connection with these crystallized calcite and also deposits in caves of stalactites and stalagmites often occur. Common with the zeolites in cavities and veins of igneous rocks as a result of alteration, and similarly though less abundant with granite, syenite, etc. A frequent mineral in metalliferous deposits, with lead, copper, silver, etc. Deposited from lime-bearing waters as calc sinter, travertine, etc., especially in connection with hot springs as at the Mammoth Hot Springs in the Yellowstone region.

Some of the best known localities for crystallized calcite are the following: Andreasberg in the Harz; the mines of Freiberg, Schneeberg, etc., in Saxony; Kapnik in Hungary; Aussig in Bohemia; Bleiberg in Carinthia; Traversella in Piedmont; Elba. In England at Alston Moor and Egremont in Cumberland; Matlock, Derbyshire; Beer Alston in Devonshire; at numerous points in Cornwall; Weardale in Durham; Stank mine, Lancashire. In twin crystals of great variety and beauty at Guanajuato, Mexico. The *Iceland spar* has been obtained from Iceland near Helgustadir on the Eskefiord. It occurs in a large cavity in basalt. The crystals, usually showing the fundamental rhombohedron, are often coated with tufts of stilbite.

In the U. States, crystallized calcite occurs in *N. York*, in St. Lawrence Co., especially at the Rossie lead mine; in Jefferson Co., near Oxbow; *dog-tooth spar*, in Niagara Co, near Lockport, with pearl spar, celestite, etc.; in Lewis Co., at Leyden and Lowville, and at the Martinsburg lead mine; at Anthony's Nose on the Hudson, formerly groups of large tabular crystals. In *N. Jersey*, at Bergen, yellow calcite with datolite, etc. In *Virginia*, at Wier's cave, *stalactites* of great beauty; also in the large caves of *Kentucky*. At the Lake Superior copper mines, complex crystals often containing scales of native copper. At Warsaw, *Illinois*, in great variety of form, lining geodes and implanted on quartz crystals; at Quincy. In *Missouri*, with dolomite near St. Louis; also with sphalerite at Joplin and other points in the zinc region in the south-western part of the state, the crystals usually scalenohedral and of a wine-yellow color. From the Bad Lands, South Dakota. In Nova Scotia, at Partridge I., a wine-colored calcite, and other interesting varieties.

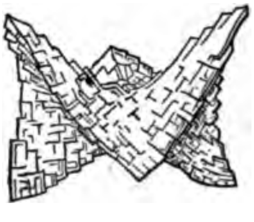
THINOLITE. A tufa deposit of calcium carbonate occurring on an enormous scale in north-western Nevada; also occurs about Mono Lake, California. It forms layers of interlaced crystals of a pale yellow or light brown color and often skeleton structure except when covered by subsequent deposit of calcium carbonate.

DOLOMITE. Pearl Spar pt.

Tri-rhombohedral. Axis $\acute{c} = 0{\cdot}8322$.

cr, $0001 \wedge 10\bar{1}1 = 43° 52'$. *MM'*, $40\bar{4}1 \wedge \bar{4}401 = 113° 53'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 73° 45'$.

706.



Habit rhombohedral, usually *r* or *M*$(40\bar{4}1)$; the presence of rhombohedrons of the second or third series after the phenacite type very characteristic. The *r* faces commonly curved or made up of sub-individuals, and thus passing into saddle-shaped forms (Fig. 706). Also granular, coarse or fine, resembling ordinary marble.

Cleavage: *r* perfect. Fracture subconchoidal. Brittle. H. = 3·5–4.

G. = 2·8–2·9. Luster vitreous, inclining to pearly in some varieties. Color white, reddish, or greenish white; also rose-red, green, brown, gray, and black. Transparent to translucent. Optically —. $\omega_y = 1·68174$ Na. $\epsilon_y = 1·50256$ Na, Fizeau.

Comp.—Carbonate of calcium and magnesium $(Ca,Mg)CO_3$; for normal dolomite $CaMgC_2O_6$ or $CaCO_3.MgCO_3$ = Carbon dioxide 47·9, lime 30·4, magnesia 21·7 = 100, or Calcium carbonate 54·35, magnesium carbonate 45·65 = 100. Varieties occur in which the ratio of the two carbonates varies from 1 : 1. The carbonates of iron and manganese also sometimes enter; rarely cobalt and zinc carbonates.

Pyr., etc.—B.B. acts like calcite. Fragments thrown into cold acid, unlike calcite, are only very slowly acted upon, if at all, while in powder in warm acid the mineral is readily dissolved with effervescence. The ferriferous dolomites become brown on exposure.

Diff.—Resembles calcite (see p. 357), but generally to be distinguished in that it does not effervesce readily in the mass in cold acid.

Obs.—Massive dolomite constitutes extensive strata, called limestone strata, in various regions, as in the dolomite region of the southern Tyrol. Crystalline and compact varieties are often associated with serpentine and other magnesian rocks, and with ordinary limestones. Some prominent localities are: Leogang in Salzburg; Schemnitz and Kapnik in Hungary; Freiberg in Saxony. In Switzerland, at Bex, in crystals; also in the Binnenthal; Traversella in Piedmont; Campolongo.

In the U. States, in *Vermont*, at Roxbury. In *N. Jersey*, at Hoboken. In *N. York*, at Lockport, Niagara Falls, etc.; at the Tilly Foster iron mine, Brewster, Putnam Co., with magnetite, chondrodite. In saddle-shaped crystals with the sphalerite of Joplin, *Missouri*. In *N. Car.*, at Stony Point, Alexander Co.

Named after Dolomieu (1750–1801), who announced some of the marked characteristics of the rock in 1791—its not effervescing with acids, while burning like limestone, and solubility after heating in acids.

Ankerite. $CaCO_3.(Mg,Fe,Mn)CO_3$, or for normal ankerite $2CaCO_3.MgCO_3.FeCO_3$. In rhombohedral crystals; $rr' = 73° 48'$; also crystalline massive, granular, compact. G. = 2·95–3·1. Color white, gray, reddish. Occurs with siderite at the Styrian mines, etc. With the hematite of northern New York.

MAGNESITE.

Rhombohedral Axis: $\acute{c} = 0·8112$. $rr' = 72° 36'$. Crystals rare, usually rhombohedral, also prismatic. Commonly massive; granular cleavable to very compact; earthy.

Cleavage: r perfect. Fracture flat conchoidal. Brittle. H. = 3·5–4·5. G. = 3·0–3·12, cryst. Luster vitreous; fibrous varieties sometimes silky. Color white, yellowish, or grayish white, brown. Transparent to opaque. Optically —. Double refraction strong.

Comp.—Magnesium carbonate, $MgCO_3$ = Carbon dioxide 52·4, magnesia 47·6 = 100. Iron carbonate is often present.

Breunnerite contains several p. c. of FeO; G. = 3–3·2; white, yellowish, brownish, rarely black and bituminous; often becoming brown on exposure, and hence called *Brown Spar*.

Pyr., etc.—B.B. resembles calcite and dolomite, and like the latter is but slightly acted upon by cold acids; in powder is readily dissolved with effervescence in warm hydrochloric acid.

Obs.—Found in talcose schist, serpentine and other magnesian rocks, also gypsum; as veins in serpentine, or mixed with it so as to form a variety of verd-antique marble. Occurs at Hrubschütz in Moravia; at Kraubat and Maria-Zell, Styria; Greiner in the Zillerthal, Tyrol; Snarum, Norway.

In the *U. S.*, at Bolton, Mass.; at Roxbury, veining serpentine; at Barehills, near Baltimore, Md.; in Penn., in crystals at West Goshen, Chester Co.; near Texas, Lancaster Co.; in Tulare, Alameda Cos., California. A white saccharoidal magnesite resembling statuary marble has been found as loose blocks on an island in the St. Lawrence River, near the Thousand Island Park.

Intermediate between magnesite and siderite are:

Mesitite. $2MgCO_3.FeCO_3$. $rr' = 72° 46'$. G. = 3·35–3·36. Usually in flat rhombohedrons (e, $01\bar{1}2$) with rounded faces. Traversella, Piedmont.

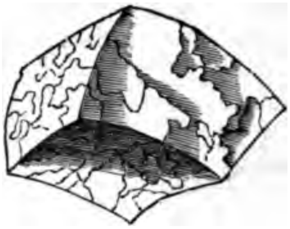
Pistomesite. $MgCO_3.FeCO_3$ = Magnesium carbonate 42·0, iron carbonate 58·0 = 100. $rr' = 72° 42'$. G. = 3·42. Thurnberg, Salzburg; also Traversella.

SIDERITE. Chalybite, Spathic Iron. Eisenspath *Germ.*

Rhombohedral. Axis $\dot{c}$ = 0·8184.

cr, $0001 \wedge 10\bar{1}1 = 43° 23'$. rr', $10\bar{1}1 \wedge \bar{1}101 = 73° 0'$.
cM, $0001 \wedge 40\bar{4}1 = 75° 11'$. MM', $40\bar{4}1 \wedge \bar{4}401 = 113° 42'$.
cs, $0001 \wedge 05\bar{5}1 = 78° 3'$. ss', $05\bar{5}1 \wedge \bar{5}051 = 115° 50'$.
cd, $0001 \wedge 08\bar{8}1 = 82° 28'$. dd', $0881 \wedge \bar{8}081 = 118° 18\frac{1}{2}'$.

707.



Crystals commonly rhombohedral r or e, the faces often curved and built up of sub-individuals like dolomite. Often cleavable massive to coarse or fine granular. Also in botryoidal and globular forms, subfibrous within, occasionally silky fibrous; compact and earthy.

Cleavage: r perfect. Fracture uneven or subconchoidal. Brittle. H. = 3·5–4. G. = 3·83–3·88. Luster vitreous, inclining to pearly. Color ash-gray, yellowish gray, greenish gray, also brown and brownish red, rarely green; and sometimes white. Streak white. Translucent to subtranslucent. Optically —. Double refraction strong.

Comp.—Iron protocarbonate, $FeCO_3$ = Carbon dioxide 37·9, iron protoxide 62·1 = 100 (Fe = 48·2 p. c.). Manganese may be present (as in *oligonite*), also magnesium and calcium.

Pyr., **etc.**—In the closed tube decrepitates, gives off CO_2, blackens and becomes magnetic. B.B. blackens and fuses at 4·5. With the fluxes reacts for iron, and with soda and niter on platinum foil generally gives a manganese reaction. Only slowly acted upon by cold acid, but dissolves with brisk effervescence in hot hydrochloric acid. Exposure to the atmosphere darkens its color, rendering it often of a blackish-brown or brownish-red color.

Diff.—Characterized by rhombohedral form and cleavage. Specific gravity higher than that of calcite, dolomite and ankerite. Resembles some sphalerite but lacks the resinous luster, differs in cleavage angle and yields CO_2 (not H_2S) with hydrochloric acid.

Obs.—Occurs in many of the rock strata, in gneiss, mica slate, clay slate, and as clay iron-stone in connection with the Coal formation and many other stratified deposits. It is often associated with metallic ores. At Freiberg it occurs in silver mines. In Cornwall it accompanies tin. It is also found accompanying copper and iron pyrites, galena, chalcocite, tetrahedrite. Occasionally it is to be met with in trap rocks as *spherosiderite* in globular concretions. Extensive deposits occur in the Eastern Alps, in Styria and Carinthia. At Harzgerode in the Harz, it occurs in fine crystals in gray-wacke; also in Cornwall of varied habit at many localities: at Alston-Moor, and Tavistock, Devonshire. Fine cleavage masses occur with cryolite in Greenland.

In the United States, in *Vermont*, at Plymouth. In *Mass.*, at Sterling. In *Conn.*, at Roxbury, an extensive vein in quartz, traversing gneiss. In *N. York*, a series of deposits occur in Columbia Co.; at the Rossie iron mines, St. Lawrence Co. In *N. Carolina*, at Fentress and Harlem mines. The argillaceous carbonate, in nodules and beds (clay ironstone), is abundant in the coal regions of Penn., Ohio, and many parts of the country. In a clay-bed under the Tertiary along the west side of Chesapeake Bay for 50 m.

RHODOCHROSITE. Dialogite. Manganspath, Himbeerspath, *Germ.*

Rhombohedral. Axis $\dot{c}$ = 0·8184, $rr' = 73° 0'$. Distinct crystals not common; usually the rhombohedron r; also e, with rounded striated faces.

Cleavable, massive to granular massive and compact. Also globular and botryoidal, with columnar structure, sometimes indistinct; incrusting.

Cleavage: *r* perfect. Fracture uneven. Brittle. H. = 3·5–4·5. G. = 3·45–3·60 and higher. Luster vitreous, inclining to pearly. Color shades of rose-red; yellowish gray, fawn-colored, dark red, brown. Streak white. Translucent to subtranslucent. Optically −.

Comp.—Manganese protocarbonate, $MnCO_3$ = Carbon dioxide 38·3, manganese protoxide 61·7 = 100. Iron carbonate is usually present even up to 40 p. c., as in *manganosiderite;* sometimes the carbonate of calcium, as in *manganocalcite,* also magnesium, zinc, and rarely cobalt.

Pyr., etc.—B.B. changes to gray, brown, and black, and decrepitates strongly, but is infusible. With salt of phosphorus and borax in O.F. gives an amethystine-colored bead, in R.F. becomes colorless. With soda on platinum foil a bluish-green manganate. Dissolves with effervescence in warm hydrochloric acid. On exposure to the air changes to brown, and some bright rose-red varieties become paler.

Diff.—Characterized by its pink color, rhombohedral form and cleavage, effervescence in acids.

Obs.—Occurs commonly in veins along with ores of silver, lead and copper, and with other ores of manganese. Found at Schemnitz and Kapnik in Hungary; Nagyág in Transylvania; at Freiberg in Saxony; at Diez near Oberneisen in Nassau; at Daaden, Rheinprovinz; at Moet-Fontaine in the Ardennes, Belgium. In the U. S., at Branchville, Conn.; in New Jersey, with franklinite at Mine Hill, Franklin Furnace. In Colorado, at the John Reed mine, Alicante, Lake Co., in beautiful clear rhombohedrons; also at the Oulay mine, near Lake City. In Montana, at Butte City. Abundant at the silver mines of Austin, Nevada. At Placentia Bay, Newfoundland.

Named *rhodochrosite* from ῥόδον, a *rose,* and χρῶσις, *color;* and *dialogite,* from διαλογή, *doubt.*

SMITHSONITE. Calamine pt. Zinkspath. Dry-bone *Miners.*

Rhombohedral. Axis $\dot{c}$ = 0·8063. rr' = 72° 20′. Rarely well crystallized; faces *r* generally curved and rough. Usually reniform, botryoidal, or stalactitic, and in crystalline incrustations; also granular, and sometimes impalpable, occasionally earthy and friable.

Cleavable: *r* perfect. Fracture uneven to imperfectly conchoidal. Brittle. H. = 5. G. = 4·30–4·45. Luster vitreous, inclining to pearly. Streak white. Color white, often grayish, greenish, brownish white, sometimes green, blue and brown. Subtransparent to translucent. Optically −.

Comp.—Zinc carbonate, $ZnCO_3$ = Carbon dioxide 35·2, zinc protoxide 64·8 = 100. Iron carbonate is often present (as in *monheimite*); also manganese and cobalt carbonates; further calcium and magnesium carbonates in traces; rarely cadmium and indium.

Pyr., etc.—In the closed tube loses carbon dioxide, and, if pure, is yellow while hot and white on cooling B.B. infusible; moistened with cobalt solution and heated in O.F. gives a green color on cooling. With soda on charcoal coats the coal with the oxide, which is yellow while hot and white on cooling; this coating, moistened with cobalt solution, gives a green color after heating in O.F. Soluble in hydrochloric acid with effervescence.

Diff.—Distinguished from calamine, which it often closely resembles by its effervescence in acids.

Obs.—Found both in veins and beds, especially in company with galena and sphalerite; also with copper and iron ores. It usually occurs in calcareous rocks, and is generally associated with calamine, and sometimes with limonite. It is often produced by the action upon zinc sulphide of carbonated waters.

Found at Nerchinsk in Siberia; at Dognaczka in Hungary; Bleiberg and Raibel in Carinthia; Wiesloch in Baden; Moresnet in Belgium; Altenberg. In the province of Santander, Spain, at Puente Viesgo. In England, at Roughten Gill, Alston Moor, near Matlock, in the Mendip Hills, and elsewhere; in Scotland, at Leadhills; in Ireland, at Donegal. At Laurion, Greece, varieties of many colors.

In the U. States, in *Penn.*, at Lancaster abundant, the var. called "dry-bone"; at the Ueberroth mine, near Bethlehem, in scalenohedrons. In *Wisconsin*, at Mineral Point, Shullsburg, etc., pseudomorphs after sphalerite and calcite. In *Minnesota*, at Ewing's diggings, N. W. of Dubuque, etc. In south-western *Missouri* associated with sphalerite and calamine. In *Arkansas*, at Calamine, Lawrence Co.; in Marion Co. A pink cobaltiferous variety occurs at Boleo, Lower California.

Named after James Smithson (1754–1829), who founded the Smithsonian Institution in Washington. The name calamine is frequently used in England, cf. calamine, p. 446.

Sphaerocobaltite. Cobalt protocarbonate, $CoCO_3$. Kobaltspath *Germ.* Rhombohedral. In small spherical masses, with crystalline surface, rarely in crystals. G. = 4·02–4·13. Color rose-red. From Schneeberg, Saxony.

---

2. Aragonite Group. RCO_3. Orthorhombic.

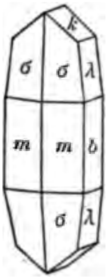
For list of species, see p. 353.

ARAGONITE.

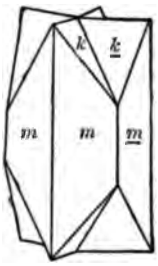
Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}62244 : 1 : 0{\cdot}72056$.

mm''', $110 \wedge 1\bar{1}0 = 63° 48'$.
kk', $011 \wedge 0\bar{1}1 = 71° 33'$.
pp', $111 \wedge \bar{1}11 = 86° 24\tfrac{1}{2}'$.
pp''', $111 \wedge 1\bar{1}1 = 50° 27'$.

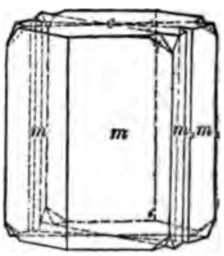
708.



709.



710.



Crystals often acicular, and characterized by the presence of acute domes or pyramids. Twins: tw. pl. *m* commonly repeated, producing pseudohexagonal forms (see p. 127, Figs. 398, 399 and 710). Also globular, reniform, and coralloidal shapes; sometimes columnar, straight or divergent; also stalactitic; incrusting.

Cleavage: *b* distinct; also *m*; *k* (011) imperfect. Fracture subconchoidal. Brittle. H. = 3·5–4. G. = 2·93–2·95. Luster vitreous, inclining to resinous on surfaces of fracture. Color white; also gray, yellow, green and violet; streak uncolored. Transparent to translucent. Optically —. Ax. pl. ∥ *a*. Bx ⊥ *c*. Dispersion $\rho > v$ small. $2E_y = 30° 54'$. $\beta_y = 1{\cdot}6816$.

Comp.—Calcium carbonate, $CaCO_3$ = Carbon dioxide 44·0, lime 56·0 = 100. Some varieties contain a little strontium, others lead, and rarely zinc.

Var.—*Ordinary.* (*a*) Crystallized in simple or compound crystals, the latter much the most common; often in radiating groups of acicular crystals. Columnar; also fine fibrous with silky luster. (*c*) Massive.

Stalactitic or *stalagmitic:* Either compact or fibrous in structure, as with calcite; *Sprudelstein* is stalactitic from Carlsbad. *Coralloidal:* In groupings of delicate interlacing and coalescing stems, of a snow-white color, and looking a little like coral; often called *Flos-ferri* (Eisenblüthe *Germ.*). *Tarnowitzite* is a kind containing lead carbonate (4 to 8 p. c.), from Tarnowitz in Silesia; with G. = 2·99.

Pyr., etc.—B B. whitens and falls to pieces, and sometimes, when containing strontia, imparts a more intensely red color to the flame than lime; otherwise reacts like calcite.

Diff.—Distinguished from calcite by higher specific gravity and absence of rhombohedral cleavage; from the zeolites (*e.g.*, natrolite), etc., by effervescence in acid. Strontianite and witherite are fusible, higher in specific gravity and yield distinctive flames B.B. The resinous luster on fracture surfaces is to be noted.

Obs.—The most common repositories of aragonite are beds of gypsum; also beds of iron ore, as the Styrian mines, where it occurs in coralloidal forms, and is denominated *flos-ferri*, "*flower of iron*"; in basalt; occasionally it occurs in lavas; often associated with copper and iron pyrites, galena, and malachite. It constitutes the pearly layer of shells.

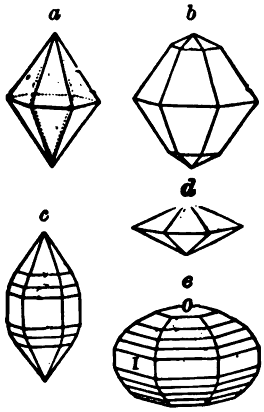
First discovered in Aragon, Spain (whence its name), at Molina and Valencia, in six-sided prisms, with gypsum. Prominent localities are Bilin, Bohemia; Leogang in Salzburg, Austria; Herrengrund, Hungary; with sulphur in Sicily in fine prisms; also at Alston Moor, fine tapering crystals.

In fibrous crusts at Hoboken, N. J.; at Edenville and Rossie, N. Y.; Wood's Mine, Lancaster Co., Penn.; Warsaw, Ill., lining geodes; Mine-la-Motte, Mo., in crystals. *Flos-ferri* in the Organ Mts., New Mexico.

WITHERITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·6032 : 1 : 0·7302$. Crystals always repeated twins, simulating hexagonal pyramids, Fig. 711 (cf. Fig. 557, p. 227). Also massive, columnar or granular.

711.



Cleavage: *b* distinct; *m* imperfect. Fracture uneven. Brittle. H. = 3–3·75. G. = 4·27–4·35. Luster vitreous, inclining to resinous on surfaces of fracture. Color white, yellowish, grayish. Streak white. Subtransparent to translucent.

Comp.—Barium carbonate, $BaCO_3$ = Carbon dioxide 22·3, baryta 77·7 = 100.

Pyr., etc.—B.B. fuses at 2 to a bead, coloring the flame yellowish green; after fusion reacts alkaline. B.B. on charcoal with soda fuses easily, and is absorbed by the coal. Soluble in dilute hydrochloric acid; this solution, even when very much diluted, gives with sulphuric acid a white precipitate which is insoluble in acids.

Diff.—Distinguished by its high specific gravity; effervescence in acid; green coloration of the flame B.B. Barite is insoluble in hydrochloric acid.

Obs.—Occurs at Alston Moor in Cumberland, with galena; at Fallowfield near Hexham in Northumberland; Tarnowitz in Silesia· Leogang in Salzburg; near Lexington. Kentucky, with barite. In a silver-bearing vein near Rabbit Mt., Thunder Bay, L. Superior.

Bromlite. $(Ba,Ca)CO_3$. In pseudohexagonal pyramids (Figs. 558, 559, p. 227). Bromley Hill, near Alston, Cumberland.

STRONTIANITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·6090 : 1 : 0·7239$.

Crystals often acicular or acute spear-shaped, like aragonite. Twins: tw. pl. *m* common. Also columnar, fibrous and granular.

Cleavage: *m* nearly perfect; *b* in traces. Fracture uneven. Brittle. H. = 3·5–4. G. = 3·680–3·714. Luster vitreous; inclining to resinous on faces of fracture. Color pale asparagus-green, apple-green; also white, gray, yellow, and yellowish brown. Streak white. Transparent to translucent. Optically —. Ax. pl. ∥ *b*. Bx ⊥ *c*. Dispersion $\rho < v$ small. $2E_r = 12° 17'$.

Comp.—Strontium carbonate, $SrCO_3$ = Carbon dioxide 29·9, strontia 70·1 = 100. A little calcium is sometimes present.

Pyr., etc.—B.B. swells up, throws out minute sprouts, fuses only on the thin edges, and colors the flame strontia-red; the assay reacts alkaline after ignition. Moistened with hydrochloric acid and treated either B.B. or in the naked lamp gives an intense red color. Soluble in hydrochloric acid; the dilute solution when treated with sulphuric acid gives a white precipitate.

Diff.—Differs from related minerals, not carbonates, in effervescing with acids; has a higher specific gravity than aragonite and lower than witherite; colors the flame *red* B.B.

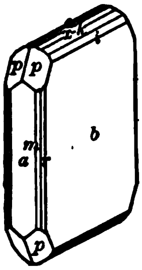
Obs.—Occurs at Strontian in Argyllshire; in Yorkshire, England; Clausthal in the Harz; Bräunsdorf, near Freiberg, Saxony; Leogang in Salzburg; near Brixlegg, Tyrol (*calciostrontianite*); in fine crystals near Hamm, Westphalia; at the Wilhelmine mine near Altahlen, Wesphalia.

In the U. States, occurs at Schoharie, N. Y.; at Muscalonge Lake; Chaumont Bay and Theresa, in Jefferson Co., N. Y., Mifflin Co., Penn.

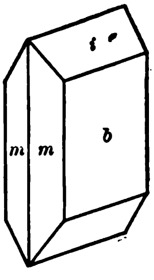
CERUSSITE. White Lead Ore. Weissbleierz *Germ.*

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·60997 : 1 : 0·72300.

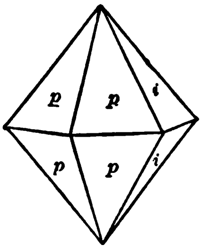
712.



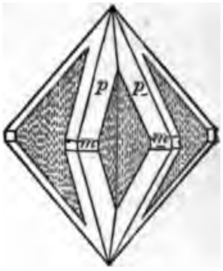
713.



714.



715.



mm''', 110 ∧ $1\bar{1}0$ = 62° 46'.
kk', 011 ∧ $0\bar{1}1$ = 71° 44'.
ii', 021 ∧ $0\bar{2}1$ = 110° 40'.
cp, 000 ∧ 111 = 54° 14'.
pp', 111 ∧ $\bar{1}11$ = 87° 42'.
pp''', 111 ∧ $1\bar{1}1$ = 49° 59½'.

Simple crystals often tabular ‖ *b*, prismatic ‖ *ă*; also pyramidal. Twins: tw. pl. *m*, very common, contact- and penetration-twins, often repeated yielding six-rayed stellate groups. Crystals grouped in clusters, and aggregates. Rarely fibrous, often granular massive and compact; earthy. Sometimes stalactitic.

Cleavage: *m* and *i* (021) distinct; *b* and *x* (012) in traces. Fracture conchoidal. Very brittle. H. = 3–3·5. G. = 6·46–6·574. Luster adamantine, inclining to vitreous, resinous, or pearly; sometimes submetallic. Color white, gray, grayish black, sometimes tinged blue or green (copper); streak uncolored. Transparent to subtranslucent. Optically −. Ax. pl. ‖ *b*. Bx ⊥ *c*. Dispersion $\rho > v$ large. Indices and axial angles, Schrauf:

	α	β	γ		2V	2E
Line D	1·80368	2·07628	2·07803	∴	8° 14'	17° 8'

Comp.—Lead carbonate, $PbCO_3$ = Carbon dioxide 16·5, lead oxide 83·5 = 100.

Pyr., etc —In the closed tube decrepitates, loses carbon dioxide, turns first yellow, and at a higher temperature dark red, but becomes again yellow on cooling. B.B. on charcoal fuses very easily, and in R.F. yields metallic lead. Soluble in dilute nitric acid with effervescence.

Diff—Characterized by high specific gravity and adamantine luster; also by yielding lead B.B. Unlike anglesite, it effervesces with nitric acid.

Obs.—Occurs in connection with other lead minerals, and is formed from galena, which, as it passes to a sulphate, may be changed to carbonate by means of solutions of calcium bicarbonate. It is found at Johanngeorgenstadt in beautiful crystals; Monte Poni, Sardinia; Friedrichssegen, Nassau; Badenweiler, Baden; at Clausthal in the Harz; at Bleiberg in Carinthia; in England, in Cornwall; at E. Tamar mine, Devonshire; near Matlock and Wirksworth, Derbyshire; at Leadhills and Wanlockhead, Scotland.

Found in *Penn.*, at Phenixville. In *Virginia*, at Austin's mines, Wythe Co. In *N. Carolina*, in King's mine. In Wisconsin and other lead mines of the northwestern States, rarely in crystals; at Hazelgreen, crystals coating galena. In *Colorado*, at Leadville, and elsewhere. In *Arizona*, at the Flux mine, Pima Co., in large crystalline masses; in crystals at the Red Cloud mine, Yuma Co.

BARYTOCALCITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c} = 0{\cdot}7717 : 1 : 0{\cdot}6254$; $\beta = 73° 52'$. In crystals; also massive.

Cleavage: *m* perfect; *c* less so. Fracture uneven to subconchoidal. Brittle. H. = 4. G. = 3·64–3·66. Luster vitreous, inclining to resinous. Color white, grayish, greenish or yellowish. Streak white. Transparent to translucent.

Comp.—Carbonate of barium and calcium, $BaCO_3.CaCO_3$ = Carbon dioxide 29·6, baryta 51·5, lime 18·9 = 100.

Pyr., etc.—B.B. colors the flame yellowish green, and at a high temperature fuses on the thin edges and assumes a pale green color; the assay reacts alkaline after ignition. With the fluxes reacts for manganese. With soda on charcoal the lime is separated as an infusible mass, while the remainder is absorbed by the coal. Soluble in dilute hydrochloric acid.

Obs.—Occurs at Alston Moor in Cumberland, in limestone with barite and fluorite.

Bismutosphärite. $Bi_2(CO_3)_3.2Bi_2O_3$. In spherical forms with radiated structure. G. = 7·42. Color yellow to gray or blackish brown. From Schneeberg, Saxony. Also sparingly at Willimantic and Portland, Conn., as a result of the alteration of bismuthinite.

Parisite. A fluocarbonate of the cerium metals. In acute double hexagonal pyramids. H. = 4·5. G. = 4·358. Color brownish yellow. From the emerald mines of the Muso valley, U. S. Colombia.

Bastnäsite. Hamartite. A fluocarbonate of the cerium metals $(RF)CO_3$. Color wax-yellow to reddish brown. From the Bastnäs mine, Riddarhyttan, Sweden. Also as an alteration product of tysonite in the granite of the Pike's Peak region in Colorado.

PHOSGENITE.

Tetragonal. Axis $\dot{c} = 1{\cdot}0876$. Crystals prismatic; sometimes tabular ‖ *c*.

Cleavage: *m*, *a* distinct; also *c*. Rather sectile. H. = 2·75–3. G. = 6·0–6·3. Luster adamantine. Color white, gray, and yellow. Streak white. Transparent to translucent. Optically +.

Comp.—Chlorocarbonate of lead, $(PbCl)_2CO_3$ or $PbCO_3.PbCl_2$ = Lead carbonate 49·0, lead chloride 51·0 = 100.

Pyr., etc.—B.B. melts readily to a yellow globule, which on cooling becomes white and crystalline. On charcoal in R.F. gives metallic lead, with a white coating of lead chloride. With a salt of phosphorus bead previously saturated with copper oxide gives the chlorine reaction. Dissolves with effervescence in dilute nitric acid.

Obs.—At Cromford near Matlock in Derbyshire; at Gibbas, Monte Poni and Montevecchio in Sardinia.

Northupite. $MgCO_3.Na_2CO_3.NaCl$. In isometric octahedrons. White to yellow or gray. From Borax Lake, San Bernardino Co., California.

B. Acid, Basic, and Hydrous Carbonates.

Teschemacherite. Acid ammonium carbonate, HNH_4CO_3. In yellowish to white crystals. G. = 1·45. From guano deposits of Africa, Patagonia, the Chincha Islands.

MALACHITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c} = 0{\cdot}8809 : 1 : 0{\cdot}4012$; $\beta = 61° 50'$.

Crystals rarely distinct, usually slender, acicular prisms ($mm''' = 75° 40'$), grouped in tufts and rosettes. Twins: tw. pl. *a* common. Commonly massive or incrusting, with surface botryoidal, or stalactitic, and structure divergent; often delicately compact fibrous, and banded in color; frequently granular or earthy.

Cleavage: *c* perfect; *b* less so. Fracture subconchoidal, uneven. Brittle. H. = 3·5–4. G. = 3·9–4·03. Luster of crystals adamantine, inclining to vitreous; of fibrous varieties more or less silky; often dull and earthy. Color bright green. Streak paler green. Translucent to subtranslucent to opaque.

Comp.—Basic cupric carbonate, $CuCO_3.Cu(OH)_2$ or $2CuO.CO_2.H_2O$ = Carbon dioxide 19·9, cupric oxide 71·9, water 8·2 = 100.

Pyr., etc.—In the closed tube blackens and yields water. B.B. fuses at 2, coloring the flame emerald-green; on charcoal is reduced to metallic copper; with the fluxes reacts like cuprite. Soluble in acids with effervescence.

Diff.—Characterized by green color and copper reactions B.B.; differs from other copper ores of a green color in its effervescence with acids.

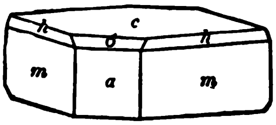
Obs.—Common with other ores of copper and as a product of their alteration; thus as a pseudomorph after cuprite and azurite. Occurs abundantly in the Ural; at Chessy in France; in Cornwall and in Cumberland, England; Rheinbreitbach; Dillenburg, Nassau; Betzdorf near Siegen. At the copper mines of Nizhni Tagilsk; with the copper ores of Cuba; Chili; at the Cobar mines and elsewhere in New South Wales; South Australia.

Occurs in *N. Jersey*, at Schuyler's mines, and at New Brunswick. In *Pennsylvania*, at Cornwall, Lebanon Co.; at the Perkiomen and Phenixville lead-mines. In *Wisconsin*, at the copper mines of Mineral Point, and elsewhere. Abundantly in fine masses and acicular crystals, with calcite at the Copper Queen mine, Bisbee, Cochise Co., *Arizona;* also in Graham Co., at Morenci (6 m. from Clifton), in stalactitic forms of malachite and azurite in concentric bands. At the Santa Rita mines, Grant Co., and elsewhere in *New Mexico*. Tintic district, *Utah*. Named from μαλαχή, *mallows*, in allusion to the green color.

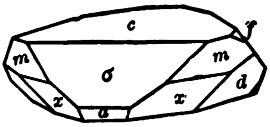
AZURITE. Kupferlasur *Germ.*

Monoclinic. Axes: $\grave{a} : \bar{b} : \acute{c}$ = 0·8501 : 1 : 0·8805; β = 87° 36′.

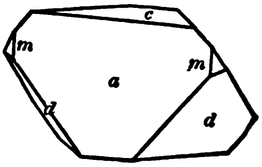
716.



717.



718.



mm‴, 110 ∧ $1\bar{1}0$ = 80° 41′.
ac, 100 ∧ 001 = 87° 36′.
cσ, 001 ∧ 101 = 44° 46′.
ll′, 023 ∧ $0\bar{2}3$ = 60° 47′.

pp′, 021 ∧ $0\bar{2}1$ = 120° 47′.
cm, 001 ∧ 110 = 88° 10′.
cd, 001 ∧ $\bar{2}43$ = 54° 29′.
hh′, 221 ∧ $2\bar{2}1$ = 73° 56′.

Crystals varied in habit and highly modified. Also massive, and presenting imitative shapes, having a columnar composition; also dull and earthy.

Cleavage: *p* (021) perfect but interrupted; *a* less perfect; *m* in traces. Fracture conchoidal. Brittle. H. = 3·5–4. G. = 3·77–3·83. Luster vitreous, almost adamantine. Color various shades of azure-blue, passing into Berlin-blue. Streak blue, lighter than the color. Transparent to subtranslucent.

Comp.—Basic cupric carbonate, $2CuCO_3.Cu(OH)_2$ or $3CuO.2CO_2.H_2O$ = Carbon dioxide 25·6, cupric oxide 69·2, water 5·2 = 100.

Pyr., etc.—Same as in malachite.

Diff.—Characterized by its blue color; effervescence in nitric acid; copper reactions B.B.

Obs.—Occurs in splendid crystallizations at Chessy, near Lyons, whence it derived the name *Chessy Copper* or *chessylite*. Also in fine crystals in Siberia; Moldawa in the Banat; at Wheal Buller, near Redruth in Cornwall; in Devonshire and Derbyshire, England; Cobar mines and elsewhere in New South Wales; South Australia.

Occurs in *Penn.*, at Phenixville, in crystals. In *N. Jersey*, near New Brunswick. In *Wisconsin*, near Mineral Point. In *Arizona*, at the Longfellow and other mines in Graham

Co.; with malachite in beautiful crystals at the Copper Queen mine, Bisbee. In Grant Co., *New Mexico*. At the Mammoth mine in the Tintic district, *Utah*. In *California*, Calaveras Co., at Hughes's mine, in crystals.

Aurichalcite. A basic carbonate of zinc and copper, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$. In drusy incrustations. G. = 3·54–3·64. Luster pearly. Color pale green to sky-blue. From the Altai; Chessy, near Lyons; Rezbánya, Hungary; and elsewhere. In the U. S., at Lancaster, Pa.; the Santa Caterina Mts., Arizona; Beaver Co., Utah.

Hydrozincite. A basic zinc carbonate, perhaps $ZnCO_3.2Zn(OH)_2$. Massive, fibrous, earthy or compact, as incrustations. G. = 3·58–3·8. Color white, grayish or yellowish. Occurs at mines of zinc, as a result of alteration. In great quantities at the Dolores mine, Santander, Spain. In the U. S., at Friedensville, Pa.; at Linden, in Wisconsin.

Hydrocerussite. A basic lead carbonate, probably $2PbCO_3.Pb(OH)_2$. In thin colorless hexagonal plates. Occurs as a coating on native lead, at Långban, Sweden; with galena at Wanlockhead, Scotland.

Dawsonite. A basic carbonate of aluminium and sodium, $Na_3Al(CO_3)_3.2Al(OH)_3$. In thin incrustations of white radiating bladed crystals. G. = 2·40. Found on a feldspathic dike near McGill College, Montreal. From the province of Siena, Pian Castagnaio, Tuscany.

Thermonatrite. Hydrous sodium carbonate, $Na_2CO_3 + H_2O$. G. = 1·5–1·6. Occurs in various lakes, and as an efflorescence over the soil in many dry regions.

Nesquehonite. Hydrous magnesium carbonate, $MgCO_3 + 3H_2O$. In radiating groups of prismatic crystals. G. = 1·83–1·85. Colorless to white. From a coal mine at Nesquehoning, Schuylkill Co , Penn. See lansfordite, p. 367.

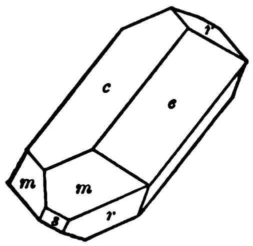
Natron. Hydrous sodium carbonate, $Na_2CO_3 + 10H_2O$. Occurring in nature only in solution, as in the soda lakes of Egypt, and elsewhere, or mixed with the other sodium carbonates.

Pirssonite. $CaCO_3.Na_2CO_3.2H_2O$. In prismatic crystals, orthorhombic-hemimorphic. Colorless to white. Borax Lake, San Bernardino, California.

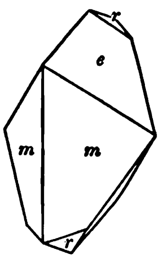
GAY-LUSSITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 1·4897 : 1 : 1·4442$; $\beta = 78° 27'$.

719.



720.



mm''', $110 \wedge 1\bar{1}0 = 111° 10'$.
ee', $011 \wedge 0\bar{1}1 = 109° 30'$.
me, $110 \wedge 011 = 42° 21'$.
rr', $\bar{1}12 \wedge \bar{1}\bar{1}2 = 69° 29'$.

Crystals often elongated ‖ $\grave{a}$; also flattened wedge-shaped. Cleavage: *m* perfect; *c* rather difficult. Fracture conchoidal. Very brittle. H. = 2–3. G. = 1·93–1·95. Luster vitreous. Color white, yellowish white. Streak uncolored to grayish. Translucent.

Comp.—Hydrous carbonate of calcium and sodium, $CaCO_3.Na_2CO_3 + 5H_2O$ = Calcium carbonate 33·8, sodium carbonate 35·8, water 30·4 = 100.

Pyr., etc.—Heated in a closed tube decrepitates and becomes opaque. B.B. fuses easily to a white enamel, and colors the flame intensely yellow. Dissolves in acids with a brisk effervescence; partly soluble in water, and reddens turmeric paper.

Obs.—Abundant at Lagunilla, near Merida, in Venezuela, in crystals disseminated at the bottom of a small lake, in a bed of clay, covering *urao*. Also abundant in Little Salt Lake, or Soda Lake, in the Carson desert near Ragtown, Nevada, deposited upon the evaporation of the water. Named after Gay Lussac, the French chemist (1778–1850).

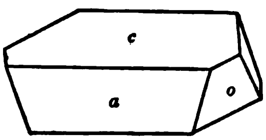
Lanthanite. $La_2(CO_3)_3 + 9H_2O$. In thin tabular crystals; also granular, earthy. G. = 2·605. Color grayish white, pink, yellowish. Found coating cerite at Bastnäs, Sweden; with zinc ores of the Saucon valley, Lehigh Co., Pa.; at the Sandford iron-ore bed, Moriah, N. Y.

TRONA. Urao.

Monoclinic. Axes: $\grave{a} : \bar{b} : \grave{c} = 2{\cdot}8460 : 1 : 2{\cdot}9700$; $\beta = 77° 23'$.

ca, $001 \wedge 100 = 77° 23'$.
co, $001 \wedge \bar{1}11 = 75° 53\frac{1}{3}'$.
oo'', $\bar{1}11 \wedge 11\bar{1} = 47° 35\frac{1}{3}'$.

721.



Often fibrous or columnar massive.

Cleavage: *a* perfect; *o*, *c* in traces. Fracture uneven to subconchoidal. H. = 2·5–3. G. = 2·11–2·14. Luster vitreous, glistening. Color gray or yellowish white. Translucent. Taste alkaline.

Comp.—$Na_2CO_3.HNaCO_3 + 2H_2O$ or $3Na_2O.4CO_2.5H_2O$ = Carbon dioxide 38·9, soda 41·2, water 19·9 = 100.

Chatard established the above composition for urao, and showed that trona, sometimes called "sesquicarbonate of soda," is an impure form of the same compound.

Pyr., etc.—In the closed tube yields water and carbon dioxide. B.B. imparts an intensely yellow color to the flame. Soluble in water, and effervesces with acids. Reacts alkaline with moistened test-paper.

Obs.—Found in the province of Fezzan, Africa, forming thin superficial crusts; at the bottom of a lake at Lagunilla, Venezuela, S. A. Efflorescences of trona occur near the Sweetwater river, Rocky Mountains. An extensive bed in Churchill Co., Nevada. In fine crystals at Borax lake, San Bernardino Co., California, with hanksite, glauberite, thenardite, etc.

Hydromagnesite. Basic magnesium carbonate, $3MgCO_3.Mg(OH)_2 + 3H_2O$. Crystals small, tufted. Also amorphous; as chalky crusts. Color and streak white. Often occurs with serpentine; thus at Hrubschütz, in Moravia; at Kraubat, Styria, etc. Also similarly near Texas, Pa.; Hoboken, N. J.

Hydrogiobertite. $MgCO_3.Mg(OH)_2 + 2H_2O$. In light gray spherical forms. From the neighborhood of Pollena, Italy.

Lansfordite. $3MgCO_3.Mg(OH)_2 + 21H_2O$. Occurs as small stalactites in the anthracite mine at Nesquehoning near Lansford, Schuylkill Co., Penn.; changed on exposure to nesquehonite.

Zaratite. Emerald Nickel. $NiCO_3$ $2Ni(OH)_2 + 4H_2O$. In mammillary incrustations; also massive, compact. Color emerald-green. Occurs on chromite at Texas, Lancaster Co., Pa.; at Swinaness, Uust, Shetland, and elsewhere.

Remingtonite. A hydrous cobalt carbonate. A rose-colored incrustation, soft and earthy. From a copper mine near Finksburg, Carroll Co., Maryland.

Tengerite. A supposed yttrium carbonate. In white pulverulent coatings. On gadolinite at Ytterby. A similar mineral is associated with the gadolinite of Llano Co., Texas.

Bismutite. Wismuthspath *Germ.* A basic bismuth carbonate, perhaps $Bi_2O_3.CO_2.H_2O$. Incrusting, or earthy and pulverulent; amorphous. G. = 6·86–6·9 Breith.; 7·67 Rg. Color white, green, yellow and gray. Occurs at Schneeberg and Johanngeorgenstadt, with native bismuth, and at Joachimsthal, etc. In the U. S., in So. Carolina, at Brewer's mine; in Gaston Co., N. C., etc.

Uranothallite. $2CaCO_3.U(CO_3)_2.10H_2O$. In scaly or granular crystalline aggregates. Color siskin-green. Occurs on uraninite at Joachimsthal, Bohemia.

Liebigite. A hydrous carbonate of uranium and calcium. In mammillary concretions, or thin coatings. Color apple-green. Occurs on uraninite near Adrianople, Turkey; also Johanngeorgenstadt and Joachimsthal.

Voglite. A hydrous carbonate of uranium, calcium and copper. In aggregations of crystalline scales. Color emerald-green to bright grass-green. From the Elias mine, near Joachimsthal, on uraninite.

Oxygen Salts.

2. SILICATES.

The Silicates are in part strictly anhydrous, in part hydrous, as the zeolites and the amorphous clays, etc. Furthermore, a large number of the silicates yield more or less water upon ignition, and in many cases it is known that they are, therefore, to be regarded as basic (or acid) silicates. The line, however, between the strictly anhydrous and hydrous silicates cannot be sharply drawn, since with many species which yield water upon ignition the part played by the elements forming the water is as yet uncertain. Furthermore, in the cases of several groups the strict arrangement must be deviated from, since the relation of the species is best exhibited by introducing the related hydrous species immediately after the others.

This chapter closes with a section including the Titanates, Silico-titanates, Titano-niobates, etc., which connect the Silicates with the Niobates and Tantalates. Some Titanates have already been included among the Oxides.

Section A. Chiefly Anhydrous Silicates.

I. Disilicates, Polysilicates.
II. Metasilicates.
III. Orthosilicates.
IV. Subsilicates.

The Disilicates, RSi_2O_5, are salts of disilicic acid, $H_2Si_2O_5$, and have an oxygen ratio of silicon to bases of 4 : 1, as seen when the formula is written after the dualistic method, $RO.2SiO_2$.

The Polysilicates, $R_2Si_3O_8$, are salts of polysilicic acid, $H_4Si_3O_8$, and have an oxygen ratio of 3 : 1, as seen in $2RO.3SiO_2$.

The Metasilicates, $RSiO_3$, are salts of metasilicic acid, H_2SiO_3, and have an oxygen ratio of 2 : 1. They have hence been called *bisilicates*.

The Orthosilicates, R_2SiO_4, are salts of orthosilicic acid, H_4SiO_4, and have an oxygen ratio of 1 : 1. They have hence been called *unisilicates*. The majority of the silicates fall into one of the last two groups.

Furthermore, there are a number of species characterized by an oxygen ratio of less than 1 : 1, *e.g.*, 3 : 4, 2 : 3, etc. These basic species are grouped as Subsilicates. Their true position is often in doubt; in most cases they are probably to be regarded as basic salts belonging to one of the other groups.

The above classification cannot, however, be carried through strictly, since there are many species which do not exactly conform to any one of the groups named, and often the true interpretation of the composition is doubtful. Furthermore, within the limits of a single group of species, connected closely in all essential characters, there may be a wide variation in the proportion of the acidic element. Thus the triclinic feldspars, placed among the polysilicates, range from the true polysilicate, $NaAlSi_3O_8$, to the orthosilicate, $CaAl_2Si_2O_8$, with many intermediate compounds, regarded as isomorphous compounds of these extremes. Similarly of the scapolite group, which, however, is included among the orthosilicates, since the majority of the compounds observed approximate to that type. The micas form another example.

I. Disilicates, RSi_2O_5. Polysilicates, $R_2Si_3O_8$.

PETALITE.

Monoclinic. Crystals rare (castorite). Usually massive, foliated cleavable (petalite).

Cleavage: *c* perfect; *o* (201) easy, *z* ($\bar{9}$05) difficult and imperfect. Fracture imperfectly conchoidal. Brittle. H. = 6–6·5. G. = 2·39–2·46. Luster vitreous, on *c* pearly. Colorless, white, gray, occasionally reddish or greenish white. Streak uncolored. Transparent to translucent.

Comp—$LiAl(Si_2O_5)_2$ or $Li_2O.Al_2O_3.8SiO_2$ = Silica 78·4, alumina 16·7, lithia, 4·9 = 100.

Pyr., etc.—Gently heated emits a blue phosphorescent light. B.B. on charcoal becomes glassy, subtransparent, and white, and melts only on the edges; gives the reaction for lithia. With borax it forms a clear, colorless glass. Not acted on by acids.

Obs.—Petalite occurs at the iron mine of Utö, Sweden, with lepidolite, tourmaline, spodumene, and quartz; on Elba (*castorite*). In the U. S., at Bolton, Mass., with scapolite; at Peru, Maine, with spodumene in albite. The name *petalite* is from *πεταλον, a leaf*, alluding to the cleavage.

Milarite. $HKCa_2Al_2(Si_2O_5)_6$. In hexagonal prisms. H. = 5·5–6. G. = 2·55–2·59. Colorless to pale green, glassy. From Val Giuf, Grisons, Switzerland.

Eudidymite. $HNaBeSi_3O_8$. In white, glassy, twinned crystals, tabular in habit. H. = 6. G. = 2·553. Occurs very sparingly in elæolite-syenite on the island Ovre-Arö, in the Langesundfiord, Norway.

Epididymite. Same composition as eudidymite. Orthorhombic. Southern Greenland.

Feldspar Group.

α. *Monoclinic Section.*

		$\grave{a} : \dot{b} : \dot{c}$	β′
Orthoclase	$KAlSi_3O_8$	0·6585 : 1 : 0·5554	116° 3′
Soda-Orthoclase	$(K,Na)AlSi_3O_8$ $(Na,K)AlSi_3O_8$		
Hyalophane	$(K_2,Ba)Al_2Si_4O_{12}$	0·6584 : 1 : 0·5512	115° 35′

β. *Triclinic Section.*

Microcline	$KAlSi_3O_8$
Soda-microcline	$(K,Na)AlSi_3O_8$
Anorthoclase	$(Na,K)AlSi_3O_8$

Albite-anorthite Series. *Plagioclase Feldspars.*

		$\breve{a} : \bar{b} : \dot{c}$	α	β	γ
Albite	$NaAlSi_3O_8$	0·6335 : 1 : 0·5577	94° 3′	116° 29′	88° 9′
Oligoclase		0·6321 : 1 : 0·5524	93° 4′	116° 23′	90° 5′
Andesine	$\left(\begin{matrix} nNaAlSi_3O_8 \\ mCaAl_2Si_2O_8 \end{matrix}\right)$	0·6357 : 1 : 0·5521	93° 23′	116° 29′	89° 59′
Labradorite		0·6377 : 1 : 0·5547	93° 31′	116° 3′	89° 54½′
Anorthite	$CaAl_2Si_2O_8$	0·6347 : 1 : 0·5501	93° 13′	115° 55′	91° 12′
Celsian	$BaAl_2Si_2O_8$		90½°		

The general characters of the species belonging in the **Feldspar Group** are as follows:

1, *Crystallization* in the monoclinic or triclinic systems, the crystals of the different species resembling each other closely in angle, in general habit, and in methods of twinning. The prismatic angle in all cases differs but a few degrees from 60° and 120°.

2, *Cleavage* in two similar directions parallel to the base *c* (001) and clinopinacoid (or brachypinacoid) *b* (010), inclined at an angle of 90° or nearly 90°. 3, *Hardness* between 6 and 6·5. 4, *Specific Gravity* varying between 2·5 and 2·9, and mostly between 2·55 and 2·75. 5, *Color* white or pale shades of yellow, red or green, less commonly dark. 6, In composition silicates of aluminium with either potassium, sodium, or calcium, and rarely barium, while magnesium and iron are always absent. Furthermore, besides the several distinct species there are many intermediate compounds having a certain independence of character and yet connected with each other by insensible gradations; all the members of the series showing a close relationship not only in composition but also in crystalline form and optical characters.

The species of the Feldspar Group are classified, first as regards form, and second with reference to composition. The *monoclinic* species include (see above): **Orthoclase**, potassium feldspar, and **Soda-orthoclase**, potassium-sodium feldspar; also **Hyalophane**, barium feldspar.

The *triclinic* species include: **Microcline** and **Anorthoclase**, potassium-sodium feldspars; **Albite**, sodium feldspar; **Anorthite**, calcium feldspar; **Celsian**, barium feldspar.

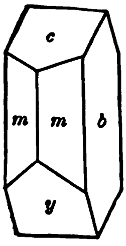
Also intermediate between albite and anorthite the isomorphous sub-species, sodium-calcium or calcium-sodium feldspars: **Oligoclase**, **Andesine**, **Labradorite**.

α. Monoclinic Section.

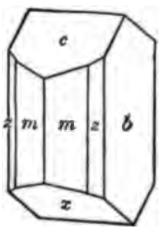
ORTHOCLASE.

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0·6585 : 1 : 0·5554$; $\beta = 63° 57'$.

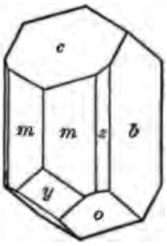
722.



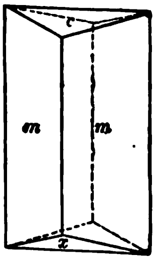
723.



724.



725.



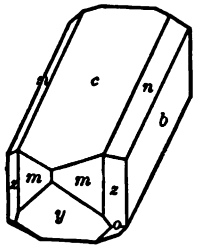
mm''', 110 ∧ $1\bar{1}0$ = 61° 13′.
zz', 130 ∧ $\bar{1}30$ = 58° 48′.
cx, 001 ∧ $\bar{1}01$ = 50° 16½′.
cy, 001 ∧ $\bar{2}01$ = 80° 18′.
cn, 001 ∧ 021 = 44° 56½′.
nn', 021 ∧ $0\bar{2}1$ = 89° 53′.
cm, 001 ∧ 110 = 67° 47′.
co, 001 ∧ $\bar{1}11$ = 55° 14½′.

Twins: tw. pl. (1) *a* (100), or tw. axis *ć*, the common *Carlsbad* twins, either of irregular penetration (Fig. 727) or contact type; the latter usually with *b* as composition-face, often then (Fig. 728) with *c* and *x* nearly in a plane, but to be distinguished by luster, cleavage, etc. (2) *n* (021), the *Baveno* twins forming nearly square prisms (Fig. 729), since *cn* = 44° 56½′, and hence *c*$\underline{c}$ = 89° 53′; often repeated as fourlings (Fig. 417, p. 129), also in square prisms, elongated ‖ *à*. (3) *c* (001), the *Manebach* twins (Fig. 730), usually contact-twins with *c* as comp.-face. Also other rarer laws.

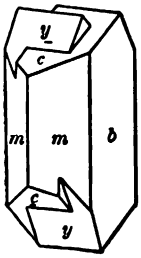
Crystals often prismatic ‖ *c̀*; sometimes orthorhombic in aspect (Figs. 723, 725) since *c* and *x* are inclined at nearly equal angles to *c̀*; also elongated ‖ *à* (Fig. 726) with *b* and *c* nearly equally developed; also thin tabular ‖ *b*: rarely tabular ‖ *a*, a face not often observed. Often massive, coarsely cleavable to granular; sometimes lamellar. Also compact crypto-crystalline, and flint-like or jasper-like.

Cleavage: *c* perfect; *b* somewhat less so; prismatic *m* imperfect, but usually more distinct parallel to one prismatic face than to the other. Parting sometimes distinct parallel to *a* (100), also to a hemi-orthodome, inclined a few degrees to the orthopinacoid; this may produce a satin-like luster or schiller (p. 190), the latter also often present when the parting is not distinct. Fracture conchoidal to uneven. Brittle. H. = 6. G. = 2·57. Luster vitreous; on *c* often pearly. Colorless, white, pale yellow and flesh-red common, gray; rarely green. Streak uncolored.

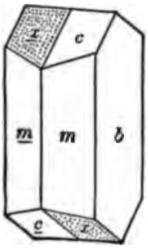
726.



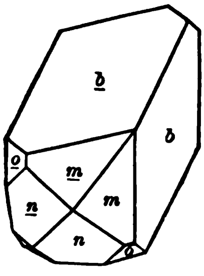
727.



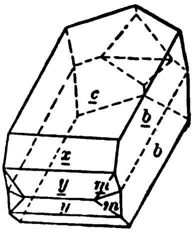
728.



729.

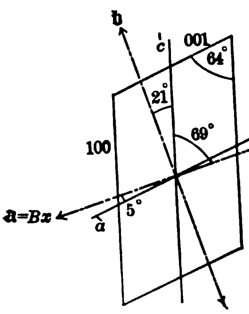


730.



Optically negative and $Bx_o \perp b$ in all cases (Fig. 731). Ax. pl. usually ⊥ *b*, sometimes ‖ *b*, also changing from the former to the latter on increase of temperature (see p. 225). For *adularia* (Dx) $Bx_{a.r} \wedge \grave{c} = -69° 11'$, $Bx_{a.bl} \wedge \grave{c} = -69° 37'$. Hence Bx_a and the extinction-direction (Fig. 731) inclined a few degrees only to *à*, or the edge *b*/*c*; thus + 3° to + 7° usually, or up to + 10° or + 12° in varieties rich in Na_2O. Dispersion $\rho > v$; also horizontal, strongly marked, or inclined, according to position of ax. pl. Axial angles variable. Birefringence low, $\gamma - \alpha = 0·007 - 0·005$. For adularia (Dx).

731.



$$\alpha_y = 1·5190,\quad \beta_y = 1·5237,\quad \gamma_y = 1·5260,$$
$$\therefore 2V_y = 69° 43'.\quad 2E_y = 121° 6'.$$

Comp., Var.—A silicate of aluminium and potassium, $KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$ = Silica 64·7, alumina 18·4, potash 16·9 = 100. Sodium is often also present, replacing part of the potassium, and sometimes exceeds it in amount; these varieties are embraced under the name soda-orthoclase (Natronorthoklas *Germ.*).

The prominent varieties depend upon crystalline habit and method of occurrence more than upon difference of composition.

1. *Adularia.* The pure or nearly pure potassium silicate. Usually in crystals, like Fig. 725 in habit; often with vicinal planes; Baveno twins common. G. = 2·565. Transparent or nearly so. Often with a pearly opalescent reflection or schiller or a delicate play of colors; some *moonstone* is here included, but the remainder belongs to albite or other of the triclinic feldspars. The original adularia (Adular) is from the St. Gothard region in Switzerland. *Valencianite*, from the silver mine of Valencia, Mexico, is adularia.

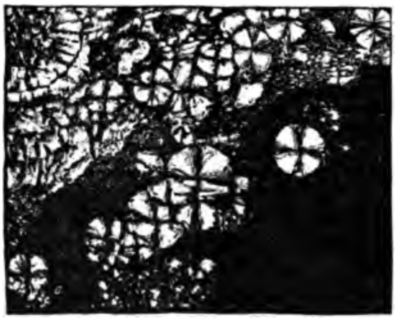
2. *Sanidine* or *glassy feldspar.* Occurs in crystals, often transparent and glassy, embedded in rhyolite, trachyte (as of the Siebengebirge), phonolite, etc. Habit often tabular ‖ *b* (hence named from σανίς, a *tablet*, or *board*); also in square prisms (*b*, *c*); Carlsbad twins common. Most varieties contain sodium as a prominent constituent, and hence belong to the soda-orthoclase.

Rhyacolite. Eisspath Werner. Occurs in glassy crystals at Monte Somma; named from ρυαξ, *stream* (lava stream).

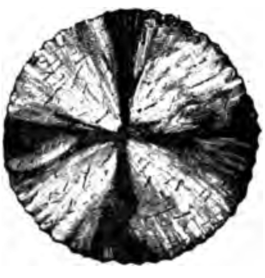
3. *Ordinary.* In crystals, Carlsbad and other twins common; also massive or cleavable, varying in color from white to pale yellow, red or green, translucent; sometimes aventurine. Here belongs the common feldspar of granitoid rocks or granite veins. Usually contains a greater or less percentage of soda (soda-orthoclase). Compact cryptocrystalline orthoclase makes up the mass of much felsite; but to a greater or less degree admixed with quartz; of various colors, from white and brown to deep red. Much of what has been called orthoclase, or common potash feldspar, has proved to belong to the related triclinic species, microcline. Cf. p. 374 on the relations of the two species. Chesterlite and Amazon stone are microcline; also most aventurine orthoclase. *Loxoclase* contains sodium in considerable amount (7·6 Na_2O). From Hammond, St. Lawrence Co., N. Y. *Murchisonite* is a flesh-red feldspar similar to perthite (p. 373), with gold-yellow reflections in a direction ⊥ *b* and nearly parallel to 701 or 801 (p. 371). From Dawlish and Exeter, England.

The spherulites noted in some volcanic rocks, as in the rhyolite of Obsidian Cliff in the Yellowstone Park, are believed to consist essentially of orthoclase needles with quartz. These are shown in Figs. 732 and 733 (from Iddings; much magnified) as they appear in polarized light (crossed nicols).

732.



733.



Pyr., etc.—B.B. fuses at 5; varieties containing much soda are more fusible. Loxoclase fuses at 4. Not acted upon by acids.

Diff.—Characterized by its crystalline form and the two cleavages at right angles to each other; harder than barite and calcite; not attacked by acids; difficultly fusible. Massive corundum is much harder and has a higher specific gravity.

Distinguished in rock sections by its low refraction (low relief) and low interference-colors, which last scarcely rise to white of the first order—hence lower than those of quartz; also by its biaxial character in convergent light and by the distinct cleavages. It is colorless in ordinary light and may be limpid, but is frequently turbid and brownish from the presence of very minute scales of kaolin due to alteration from weathering; this change is especially common in the older granular rocks, as granite and gneiss.

Obs.—Orthoclase in its several varieties belongs especially to the crystalline rocks, occurring as an essential constituent of granite, gneiss, syenite, also porphyry, further (var., *sanidine*) trachyte, phonolite, etc. In the massive granitoid rocks it is seldom in distinct, well-formed, separable crystals, except in veins and cavities; such crystals are more common, however, in volcanic rocks like trachyte.

Adularia occurs in the crystalline rocks of the central and eastern Alps, associated with smoky quartz and albite, also titanite, apatite, etc.; the crystals are often coated with chlorite; also on Elba. Fine crystals of orthoclase, often twins, are obtained from Baveno, Lago Maggiore; the Fleimsthal, a red variety; Valfloriana; Bodenmais, Carlsbad and Elbogen in Bohemia; Striegau, etc., in Silesia. Also Arendal in Norway, and near Shaitansk in the Ural; Land's End and St. Agnes in Cornwall; the Mourne Mts., Ireland, with beryl and topaz. From Tamagama Yama, Japan, with topaz and smoky quartz. *Moonstone* is brought from Ceylon.

In the U. States, orthoclase is common in the crystalline rocks of New England, also of States south, further Colorado, California, etc. Thus at the Paris tourmaline locality. In *N. Hamp.*, at Acworth. In *Mass.*, at South Royalston and Barre. In *Conn.*, at Haddam and Middletown, in large coarse crystals. In *N. York*, in St. Lawrence Co., at Rossie; at Hammond (*loxoclase*); in Lewis Co., in white limestone near Natural Bridge; at Amity and Edenville. In *Penn.*, in crystals at Leiperville, Mineral Hill, Delaware Co.; sunstone in Kennett Township. In *N. Car.*, at Washington Mine, Davidson Co. In *Colorado*, at the summit of Mt. Antero, Chaffee Co., in fine crystals, often twins; at Gunnison; Black Hawk; Kokoma, Summit Co., also at other points. Also similarly in Nevada and California.

Orthoclase is frequently altered, especially through the action of carbonated or alkaline waters; the final result is often the removal of the potash and the formation of kaolin. Steatite, talc, chlorite, leucite, mica, laumontite, occur as pseudomorphs after orthoclase; and cassiterite and calcite often replace these feldspars by some process of solution and substitution.

PERTHITE. As first described, a flesh-red aventurine feldspar from Perth, Ontario, Canada, called a soda-orthoclase, but shown by Gerhard to consist of interlaminated orthoclase and albite. Many similar occurrences have since been noted, as also those in which microcline and albite are similarly interlaminated, the latter called *microcline-perthite*, or microcline-albite-perthite; this is true in part of the original perthite. When the structure is discernible only with the help of the microscope it is called *microperthite*. Brögger has investigated not only the microperthites of Norway (Orthoklasmikroperthit, Mikroklinmikroperthit), but also other feldspars characterized by a marked schiller; he assumes the existence of an extremely fine interlamination of albite and orthoclase ‖ 801, not discernible by the microscope (cryptoperthite), and connected with secondary planes of parting ‖ 100 or ‖ $\bar{8}01$, which is probably to be explained as due to incipient alteration.

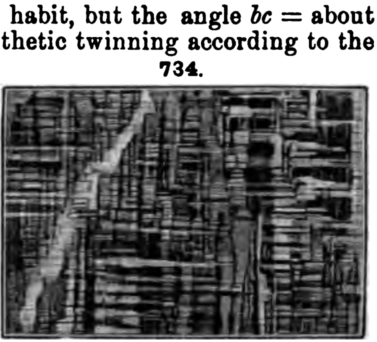
Hyalophane. $(K_2,Ba)Al_2(SiO_3)_4$ or $K_2O.BaO.2Al_2O_3.8SiO_2$. Silica 51·6, alumina 21·9, baryta 16·4, potash 10·1 = 100. In crystals, like adularia in habit (Fig. 725, p. 370); also massive. Cleavage: *c* perfect; *b* somewhat less so. H. = 6–6·5. G. = 2·805. Occurs in a granular dolomite in the Binnenthal, Switzerland; also at the manganese mine of Jakobsberg, Sweden. Some other feldspars containing 7 to 15 p. c. BaO have been described (cf. also celsian, p. 381).

β. Triclinic Section.

MICROCLINE.

Triclinic. Near orthoclase in angles and habit, but the angle *bc* = about 89° 30′. Twins: like orthoclase, also polysynthetic twinning according to the albite and pericline laws (p. 375), common, producing two series of fine lamellæ nearly at right angles to each other, hence the characteristic grating-structure of a basal section in polarized light (Fig. 734). Also massive cleavable to granular compact.

734.



Cleavage: *c* perfect; *b* somewhat less so; *M* (1$\bar{1}$0) sometimes distinct; *m* (110) also sometimes distinct, but less easy. Fracture uneven. Brittle. H. = 6–6·5. G. = 2·54–2·57. Luster vitreous, on *c* sometimes pearly. Color white to pale cream-yellow, also red, green. Transparent to translucent.

Optically —. Ax. pl. nearly perpendicular (82°–83°) to *b*. Bx_o inclined 15° 26′ to a normal to *b*. Dispersion $\rho < v$ about Bx_o. Extinction-angle on *c*, + 15° 30′; on *b*, + 5° to 6° (Fig. 739, p. 375). $2H_{a.r} = 88°$ to 89°, Dx.

The essential identity of orthoclase and microcline has been urged by Mallard and Michel-Lévy on the ground that the properties of the former would belong to an aggregate of submicroscopic twinning lamellæ of the latter, according to the albite and pericline laws.

Comp., Var.—Like orthoclase, $KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$ = Silica 64·7, alumina 18·4, potash 16·9 = 100. Sodium is usually present in small amount: sometimes prominent, as in soda-microcline.

Pyr.—As for orthoclase.

Diff.—Resembles orthoclase but distinguished by optical characters (*e.g.*, the grating structure in polarized light, Fig. 734); also often shows fine twinning-striations on a basal surface (albite law).

Obs.—Occurs under the same conditions as much common orthoclase. The beautiful *amazonstone* from the Ural, also that occurring in fine groups of large crystals of deep color in the granite of Pike's Peak, Colorado, is microcline. *Chesterlite* from Poorhouse quarry, Chester Co., Penn., and the aventurine feldspar of Mineral Hill, Penn., belong here. A pure variety occurs at Magnet Cove, Arkansas. Ordinary microline is common at many points.

Anorthoclase. A triclinic feldspar with a cleavage-angle, *bc*, varying but little from 90°. Form like that of the ordinary feldspars. Twinning as with orthoclase; also polysynthetic according to the albite and pericline laws; but in many cases the twinning laminæ very narrow and hence not distinct. Rhombic section (see p. 375) inclined on *b*, 4° to 6° to edge *b/c*. G. = 2·57–2·60. Cleavage, hardness, luster, and color as with other members of the group. Optically —. Extinction-angle on *c*, + 5° 45′ to + 2°; on *b*, 6° to 9°·8. Bx_a nearly ⊥ *y*. Dispersion $\rho > v$; horizontal distinct. Axial angle variable with temperature, becoming in part monoclinic in optical symmetry between 86° and 264° C., but again triclinic on cooling; this is true of those containing little calcium.

Chiefly a soda-potash feldspar, $NaAlSi_3O_8$ and $KAlSi_3O_8$, the sodium silicate usually in larger proportion (2 : 1, 3 : 1, etc.), as if consisting of albite and orthoclase molecules. Calcium ($CaAl_2Si_2O_8$) is also present in relatively very small amount.

These triclinic soda-potash feldspars are chiefly known from the andesitic lavas of Pantelleria. Most of these feldspars come from a rock, called pantellerite. Also prominent from the augite-syenite of southern Norway and from the "Rhomben-porphyr" near Christiania. Here is referred also a feldspar in crystals, tabular ∥ *c*, and twinned according to the Manebach and less often Baveno laws occurring in the lithophyses of the rhyolyte of Obsidian Cliff, Yellowstone Park. It shows the blue opalescence in a direction parallel with a steep orthodome (cf. p. 371).

Albite-Anorthite Series. *Plagioclase Feldspars.**

Between the isomorphous species

ALBITE	$NaAlSi_3O_8$	Ab
ANORTHITE	$CaAl_2Si_2O_8$	An

there are a number of intermediate subspecies, regarded, as urged by Tschermak, as isomorphous mixtures of these molecules, and defined according to the ratio in which they enter; their composition is expressed in general by the formula Ab_nAn_m. They are:

OLIGOCLASE	Ab_6An_1	to	Ab_3An_1
ANDESINE	Ab_3An_1	to	Ab_1An_1
LABRADORITE	Ab_1An_1	to	Ab_1An_3
and Bytownite	Ab_1An_3	to	Ab_1An_6

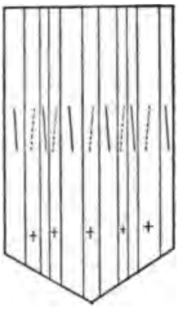
From albite through the successive intermediate compounds to anorthite with the progressive change in composition (and specific gravity), there is also a corresponding change in crystallographic form, and in certain fundamental optical properties.

---

* The triclinic feldspars of this series, in which the two cleavages *b* and *c* are oblique to each other, are often called in general *plagioclase* (from πλάγιος, *oblique*).

Crystalline form. The axial ratios and angles given on p. 369 show that these triclinic feldspars approach orthoclase closely in form, the most obvious difference being in the cleavage-angle *bc*, which is 90° in orthoclase, 86° 24′ in albite, and 85° 50′ in anorthite. There is also a change in the axial angle γ, which is 88° in albite, about 90° in oligoclase and andesine, and 91° in anorthite. This transition appears still more strikingly in the position of the "rhombic section," by which the twins according to the pericline law are united as explained below.

735.



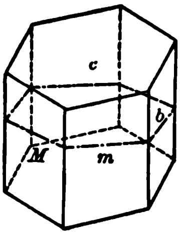
736.

Plagioclase with twinning lamellæ, Fig. 735 section | *c* (001) showing vibration-directions (cf. Fig. 739), ordinary light; Fig. 736 section in polarized light

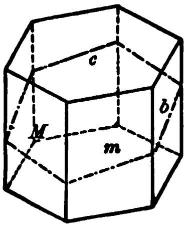
Twinning. The plagioclase feldspars are often twinned in accordance with the Carlsbad, Baveno, and Manebach laws common with orthoclase (pp. 370, 371). Twinning is also almost universal according to the *albite law*—twinning plane the brachypinacoid; this is usually polysynthetic, i.e. repeated in the form of thin lamellæ, giving rise to fine striations on the basal cleavage surface (Figs. 735, 736). Twinning is also common according to the *pericline law*—twinning axis the macrodiagonal axis $\bar{b}$; when polysynthetic this gives another series of fine striations seen on the brachypinacoid.

The composition-plane in this pericline twinning is a plane passing through the crystal in such a direction that its intersections with the prismatic faces and the brachypinacoid make equal plane angles with each other. The position of this rhombic section and the consequent direction of the striations on the brachypinacoid change rapidly with a small variation in the angle γ. In general it may be said to be approximately parallel to the base, but in albite it is inclined backward (+, Figs. 737 and 739*) and in anorthite to the front (−, Fig. 738); for the intermediate species its position varies progressively with the composition. Thus for the angle between the trace of this plane on the brachypinacoid and the edge *b/c*, we have for Albite + 22° to + 20°; for Oligoclase + 9° to + 3¼°; for Andesine + 1° to − 2°; for Labradorite − 9° to − 10°; for Anorthite − 15° to − 17°.

737.



738.



739.

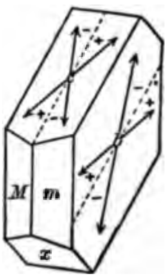


Fig. 737, Rhombic section in albite. 738, Same in anorthite. 739, Typical form showing + and − extinction-directions on *c* (001) and *b* (010).

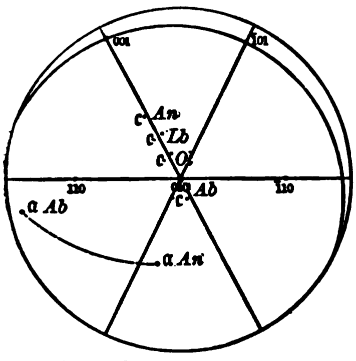
---

* The faces of this fundamental form are often lettered as follows: *c* (001) = *P*, *b* (010) = *M*, *m* (110) = *l*, *M* (1$\bar{1}$0) = *T*.

If the composition-plane is at right angles to the twinning axis in the pericline twinning, the polysynthetic lamellæ then show prominently in a basal section, together with those due to the albite twinning. Hence the grating structure characteristic of microcline.

Optical Characters. There is also a progressive change in the position of the ether-axes and the optic axial plane in passing from albite to anorthite. This is most simply exhibited by the position of the planes of light-vibration, as observed in sections parallel to the two cleavages, basal *c* and clinopinacoidal *b*, in other words the extinction-angle formed on each face with the edge *b*/*c* (cf. Fig. 739).

740.



The approximate position of the ether-axes for the different feldspars is shown in Fig. 740 (Schuster). The axis c does not vary very much from the zone *bc*, but the axis a varies widely, and hence the axial plane has an entirely different position in albite from what it has in anorthite. Furthermore albite is optically positive, that is c = Bx, while anorthite is negative or a = Bx; for certain andesines the axial angle is sensibly 90°.

The following table gives the percentage composition of the various molecular compounds of albite and anorthite, with the calculated specific gravity (Tschermak), and also certain of the optical characters connected with them. These latter values were calculated by Schuster from an equation deduced by Mallard, in which certain observed values were assumed as fundamental :*

	Ratio of Albite to Anorthite Ab_nAn_m		Percentage Composition				Extinction-angle with edge *c*/*b*	
	n : *m*	G.	SiO_2	Al_2O_3	CaO	Na_2O	on *c*	on *b*
Albite	1 : 0	2·624	68·7	19·5	0	11·8	+ 4° 30′	+ 19°
Oligoclase-albite	12 : 1	2·635	66·6	20·9	1·6	10·9	+ 3° 38′	+ 15° 35′
	6 : 1	2·645	64·9	22·1	3·0	10·0	to + 2° 45′	to + 11° 59′
Oligoclase	4 : 1	2·652	63·3	23·1	4·2	9·4	+ 1° 55′	+ 8° 17′
	2 : 1	2·671	59·9	25·4	7·0	7·7	to − 0° 35′	to − 2° 15′
Andesine	3 : 2	2·680	58·1	26·6	8·4	6·9	− 2° 12′	− 7° 58′
	1 : 1	2·694	55·6	28·3	10·4	5·7	to − 5° 10′	to − 16°
Labradorite	3 : 4	2·703	53·7	29·6	11·8	4·9	− 7° 53′	− 20° 52′
	1 : 3	2·728	49·3	32·6	15·3	2·8	to − 17° 40′	to − 29° 28′
Bytownite	1 : 4	2·735	48·0	33·4	16·3	2·3	− 21° 5′	− 31° 10′
	1 : 8	2·747	45·9	34·9	18·0	1·2	to − 28° 4′	to − 33° 40′
Anorthite	0 : 1	2·758	43·2	36·7	20·1	0	− 37°	− 36°

Diff.—In rock sections the plagioclase feldspars are distinguished by their lack of color, low refractive relief, and low interference-colors, which in good sections are mainly dark gray and scarcely rise into white of the first order; also by their biaxial character in converging light. In the majority of cases they are easily told by the parallel bands or fine lamellæ which pass through them due to the multiple twinning according to the albite law; one set of bands or twin lamellæ exhibits in general a different interference-color from the other (cf. Figs. 735, 736). They are thus distinguished not only from quartz and orthoclase, with which they are often associated, but from all the common rock-making minerals. To distinguish the different species and sub-species from one another, as albite from labradorite or andesine, is more difficult. In sections having a definite orientation (‖ c (001) and ‖ b (010)) this can generally be done by determining the extinction angles (cf. p. 375 and Fig. 739). In general in rock sections special methods are required; these are discussed by the authors referred to in the note on p. 376.

---

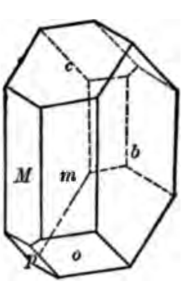
* See Tschermak, Ber. Ak. Wien, 50 (1), 566, 1865; Schuster, Min. Mitth., 3, 117, 1881, 5, 189, 1882; Mallard, Bull. Soc. Min., 4, 96, 1881. Also Michel-Lévy and other authors referred to on p. 212; further, G. F. Becker, Am. J. Sc., 5, p. 349, May 1898.

ALBITE.

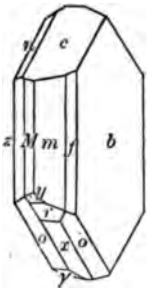
Triclinic. Axes $\breve{a} : \bar{b} : \acute{c} = 0{\cdot}6335 : 1 : 0{\cdot}5577$; $\alpha = 94° 3'$, $\beta = 116° 29'$, $\gamma = 88° 9'$.

bc, 010 ∧ 001 = 86° 24'.
mM, 110 ∧ 1$\bar{1}$0 = 59° 14'.
bm, 110 ∧ 010 = 60° 26'.
cm, 001 ∧ 110 = 65° 17'.
cM, 001 ∧ 1$\bar{1}$0 = 69° 10'.
cx, 001 ∧ $\bar{1}$01 = 52° 16'.

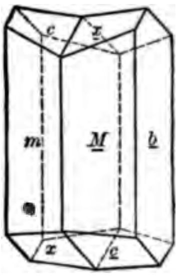
741.



742.



743.



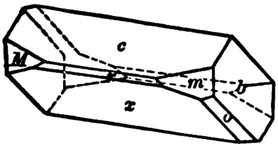
Twins as with orthoclase; also very common, the tw. pl. *b*, *albite law* (p. 375), usually contact-twins, and polysynthetic, consisting of thin lamellæ and with consequent fine striations on *c*; tw. axis $\bar{b}$, *pericline law*, contact-twins whose composition-face is the *rhombic section* (Figs. 737 and 745); often polysynthetic and showing fine striations which on *b* are inclined backward + 22° to the edge *b*/*c*.

Crystals often tabular ‖ *b*; also elongated ‖ axis $\bar{b}$, as in the variety pericline. Also massive, either lamellar or granular; the laminæ often curved, sometimes divergent; granular varieties occasionally quite fine to impalpable.

Cleavage: *c* perfect; *b* somewhat less so; *m* imperfect. Fracture uneven to conchoidal. Brittle. H. = 6–6·5. G. = 2·62–2·65. Luster vitreous; on a cleavage surface often pearly. Color white; also occasionally bluish, gray, reddish, greenish, and green; sometimes having a bluish opalescence or play of colors on *c*. Streak uncolored. Transparent to subtranslucent.

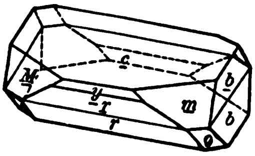
Optically +. Plane (S) ⊥ to Bx_a, inclined 100° to 102° to *c* on acute edge *b*/*c*. Extinction-angle with edge $b/c = + 4° 30'$ to 2° on *c*, and = + 20° to 15° on *b* (Fig. 737). Dispersion for Bx_a, $\rho < v$; also inclined, horizontal; for Bx_o, $\rho > v$; inclined, crossed, Dx. $2H_{a.r} =$ 80° to 84° Dx. Birefringence weak, $\gamma - \alpha = 0{\cdot}008$.

744.



Pericline.

745.



Comp.—A silicate of aluminium and sodium, $NaAlSi_3O_8$ or $Na_2O.Al_2O_3.6SiO_2$ = Silica 68·7, alumina 19·5, soda 11·8 = 100. Calcium is usually present in small amount, as anorthite ($CaAl_2Si_2O_8$), and as this increases it graduates through oligoclase-albite to oligoclase (cf. p. 376). Potassium may also be present, and it is then connected with anorthoclase and microcline.

Var.—*Ordinary.* In crystals and massive. The crystals often tabular ‖ *b*. The massive forms are usually nearly pure white, and often show wavy or curved laminæ. *Peristerite* is a whitish adularia-like albite, slightly iridescent, named from *περιστερά*, *pigeon*. *Aventurine* and *moonstone* varieties also occur. *Pericline* from the chloritic schists of the Alps is in rather large opaque white crystals, with characteristic elongation in the direction of the *b* axis, as shown in Figs. 744 and 745, and commonly twinned with this as the twinning axis (pericline law).

Pyr., etc.—B.B. fuses at 4 to a colorless or white glass, imparting an intense yellow to the flame. Not acted upon by acids.

Diff.—Resembles barite in some forms, but is harder and of lower specific gravity; does not effervesce with acid (like calcite). Distinguished optically and by the common twinning striations on *c* from orthoclase; from the other triclinic feldspars partially by specific gravity and better by optical means (see p. 376).

Obs.—Albite is a constituent of many igneous rocks, especially those of alkaline type, as granite, elæolite-syenite, diorite, etc.; also in the corresponding feldspathic lavas In *perthite* (p. 373) it is interlaminated with orthoclase or microcline, and similar aggregations, often on a microscopic scale, are common in many rocks. Albite is common also in gneiss, and sometimes in the crystalline schists. Veins of albitic granite are often repositories of the rarer minerals and of fine crystallizations of gems, including beryl, tourmaline, allanite, columbite, etc. It is found in disseminated crystals in granular limestone.

Some of the most prominent European localities are in cavities and veins in the granite or granitoid rocks of the Swiss and Austrian Alps, associated with adularia, smoky quartz, chlorite, titanite, apatite, and many rarer species: it is often implanted in parallel position upon the orthoclase. Thus in the St. Gothard region; Roc Tourné near Modane, Savoy; on Mt. Skopi (*pericline*); Tavetschthal; Schmirn, Tyrol; also Pfitsch, Rauris, the Zillerthal, Kriml, Schneeberg in Passeir in simple crystals. Also in Dauphiné in similar association; Elba. Also Hirschberg in Silesia; Penig in Saxony; with topaz at Mursinka in the Ural and near Miask in the Ilmen Mts.; Cornwall, England; Mourne Mts. in Ireland.

In the United States, in *Maine*, at Paris, with red and blue tourmalines. In *Mass*, at Chesterfield, in lamellar masses (*cleavelandite*), slightly bluish, also fine granular. In *New Hamp.*, at Acworth and Alstead. In *Conn.*, at Haddam; at the Middletown feldspar quarry; at Branchville, in fine crystals and massive. In *N. York*, at Moriah, Essex Co., of a greenish color. In *Penn.*, at Unionville, Chester Co. In *Virginia*, at the mica mines near Amelia Court-House in splendid crystallizations. In *Colorado*, in the Pike's Peak region with smoky quartz and amazon-stone.

The name *albite* is derived from *albus*, white, in allusion to its common color.

Oligoclase.

Triclinic. Axes, see p. 369 *bc*, 010 ∧ 001 = 86° 32′ Twins observed according to the Carlsbad, albite, and pericline laws. Crystals not common. Usually massive, cleavable to compact.

Cleavage: *c* perfect; *b* somewhat less so. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 2·65–2·67. Luster vitreous to somewhat pearly or waxy. Color usually whitish, with a faint tinge of grayish green, grayish white, reddish white, greenish, reddish; sometimes aventurine. Transparent, subtranslucent. Optical characters, see p. 376.

Comp., Var.—Intermediate between albite and anorthite and corresponding to Ab_6An_1 to Ab_2An_1, but chiefly to Ab_3An_1, p. 376.

Var.—1. *Ordinary*. In crystals or more commonly massive, cleavable. The varieties containing soda up to 10 p. c. are called *oligoclase-albite*. 2. *Aventurine oligoclase*, or *sunstone*, is of a grayish-white to reddish-gray color, usually the latter, with internal yellowish or reddish fire-like reflections proceeding from disseminated crystals of probably either hematite or göthite.

Pyr., etc.—B B. fuses at 3·5 to a clear or enamel-like glass. Not materially acted upon by acids.

Diff.—See orthoclase (p. 372) and albite (p. 377); also pp. 370, 376.

Obs.—Occurs in porphyry, granite, syenite, and also in different effusive rocks, as andesite. It is sometimes associated with orthoclase in granite, or other granite-like rock. Among its localities are Danviks-Zoll near Stockholm; Pargas in Finland; Shaitansk, Ural; in syenite of the Vosges; at Albula in the Grisons; Marienbad, Bohemia; Chalanches in Allemont, and Bourg d'Oisans, Dauphiné; as *sunstone* at Tvedestrand, Norway; at Hitterö; Lake Baikal.

In the United States, at Fine and Macomb, St. Lawrence Co., N. Y., in good crystals; at Danbury, Ct., with orthoclase and danburite; Haddam, Ct.; at the emery mine, Chester, Mass., granular; at Unionville, Pa., with euphyllite and corundum; Mineral Hill, Delaware Co.; at Bakersville, N. C., in clear glassy masses, showing cleavage but no twinning: Named in 1826 by Breithaupt from ὀλίγος, *little*, and κλάσις, *fracture*.

Andesine.

Triclinic. Axes, see p. 369. *bc*, 010 ∧ 001 = 86° 14′. Twins as with albite. Crystals rare. Usually massive cleavable or granular.

Cleavage: *c* perfect; *b* less so; also *M* sometimes observed. H. = 5–6. G. = 2·68–2·69. Color white, gray, greenish, yellowish, flesh-red. Luster subvitreous to pearly. Optical characters, see p. 376.

Comp.—Intermediate between albite and anorthite, corresponding to Ab : An in the ratio of 3 : 2, 4 : 3 to 1 : 1, see p. 376.

Pyr., etc.—Fuses in thin splinters before the blowpipe. Imperfectly soluble in acids.

Obs.—Observed in many granular and volcanic rocks; thus occurs in the Andes, at Marmato, as an ingredient of the rock called *andesite;* in the porphyry of l'Esterel, Dept. du Var, France; in the syenite of Alsace in the Vosges; at Vapnefiord, Iceland; Bodenmais, Bavaria. Sanford, Me., with vesuvianite. Common in the igneous rocks of the Rocky Mts.

Labradorite. Labrador Feldspar.

Triclinic. Form near that of andesine, but not accurately known (p. 369). Cleavage angle *bc* = 86° 4′. Forms and twinning similar to the other plagioclase species. Crystals often very thin tabular ‖ *b*, and rhombic in outline bounded by *cy* or *cx* (Fig. 425, p. 131). Also massive, cleavable or granular; sometimes cryptocrystalline or hornstone-like.

Cleavage: *c* perfect; *b* less so; *M* (1$\bar{1}$0) sometimes distinct. H. = 5–6. G. = 2·70–2·72. Luster on *c* pearly, passing into vitreous; elsewhere vitreous or subresinous. Color gray, brown, or greenish; sometimes colorless and glassy; rarely porcelain-white; usually a beautiful change of colors in cleavable varieties, especially ‖ *b*. Streak uncolored. Translucent to subtranslucent. Optical characters, see p. 376.

Play of colors a common character, but sometimes wanting as in some colorless crystals. Blue and green are the predominant colors; but yellow, fire-red, and pearl-gray also occur. Vogelsang regards the common blue color of labradorite as an interference-phenomenon due to its lamellar structure, while the golden or reddish schiller, with the other colors, is due to the presence of black acicular microlites and yellowish-red microscopic lamellæ, or to the combined effect of these with the blue reflections. Schrauf has examined the inclusions, their position, etc., and given the names *microplakite* and *microphyllite* to two groups of them. (See references on p. 142.)

Comp., Var.—Intermediate between albite and anorthite and corresponding chiefly to Ab : An in a ratio of from 1 : 1 to 1 : 3, p. 376.

The feldspars which lie between labradorite proper and anorthite have been embraced by Tschermak under the name *bytownite*. The original bytownite of Thomson was a greenish-white feldspathic mineral found in a boulder near Bytown (now Ottawa) in Ontario, Canada.

Pyr., etc.—B.B. fuses at 3 to a colorless glass. Decomposed with difficulty by hydrochloric acid, generally leaving a portion of undecomposed mineral.

Diff.—The beautiful play of colors is a common but not universal character. Otherwise distinguished as are the other feldspars (pp. 370, 376).

Obs.—Labradorite is an essential constituent of various igneous rocks, especially of the basic kinds, and usually associated with some member of the pyroxene or amphibole groups. Thus with hypersthene in norite, with diallage in gabbro, with some form of pyroxene in diabase, basalt, dolerite, also andesite, tephrite, etc. Labradorite also occurs in other kinds of lava, and is sometimes found in them in glassy crystals, as in those of Etna, Vesuvius, the Sandwich Islands at Kilauea.

The labradoritic massive rocks are most common among the formations of the Archæan era. Such are part of those of British America, northern New York, Pennsylvania, Arkansas; those of Greenland, Norway, Finland, Sweden, and probably of the Vosges.

On the coast of Labrador, labradorite is associated with hornblende, hypersthene, and magnetite. It is met with in many places in Quebec. Occurs abundantly through the central Adirondack region in northern New York; in the Wichita Mts., Arkansas.

Labradorite was first brought from the Isle of Paul. on the coast of Labrador, by Mr. Wolfe, a Moravian missionary, about the year 1770.

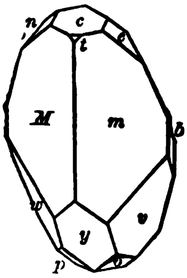
Maskelynite. In colorless isotropic grains in meteorites; composition near labradorite.

ANORTHITE. Indianite.

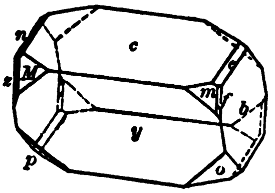
Triclinic. Axes $\breve{a} : \bar{b} : \grave{c} = 0{\cdot}6347 : 1 : 0{\cdot}5501$; $\alpha = 93° 13'$, $\beta = 115° 55\frac{1}{2}'$, $\gamma = 91° 12'$.

bc, 010 ∧ 001 = 85° 50′.
mM, 110 ∧ $1\bar{1}0$ = 59° 29′.
bm, 010 ∧ 110 = 58° 4′.
cm, 001 ∧ 110 = 65° 53′.
cM, 001 ∧ $1\bar{1}0$ = 69° 20′.
cy, 001 ∧ $\bar{2}01$ = 81° 14′.

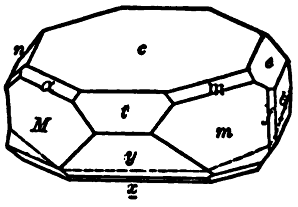
746.



747.



748.



Twins as with albite (p. 375 and p. 377). Crystals usually prismatic ‖ $\grave{c}$ (746, also Fig. 338, p. 108), less often elongated ‖ $\bar{b}$, like pericline (Fig. 747). Also massive, cleavable, with granular or coarse lamellar structure.

Cleavage: *c* perfect; *b* somewhat less so. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 2·74–2·76. Color white, grayish, reddish. Streak uncolored. Transparent to translucent.

Optically —. Ax. pl. nearly ⊥ *e* (021), and its trace inclined 60° to the edge *c*/*e* from left above behind to right in front below. Extinction-angles on *c*, — 34° to — 42° with edge *b*/*c*; on *b*, — 35° to — 43° (Fig. 739, p. 375). Dispersion $\rho < v$, also inclined. $2H_{a.r} = 84° 50'$. Birefringence stronger than with albite, $\gamma - \alpha = 0{\cdot}013$.

Comp.—A silicate of aluminium and calcium, $CaAl_2Si_2O_8$ or $CaO.Al_2O_3.2SiO_2$ = Silica 43·2, alumina 36 7, lime 20·1 = 100. Soda (as $NaAlSi_3O_8$) is usually present in small amount, and as it increases there is a gradual transition through bytownite to labradorite.

Var.—*Anorthite* was described from the glassy crystals of Somma; and *christianite* and *biotine* are the same mineral. *Thiorsauite* is the same from Iceland. *Indianite* is a white, grayish, or reddish granular anorthite from India, where it occurs as the gangue of corundum, first described in 1802 by Count Bournon. *Cyclopite* occurs in small, transparent, and glassy crystals, tabular ‖ *b*, coating cavities in the dolerite of the Cyclopean Islands and near Trezza on Etna. *Amphodelite*, *lepolite*, *latrobite* also belong to anorthite.

Pyr., etc.—B.B. fuses at 5 to a colorless glass. Anorthite from Mte. Somma, and indianite from the Carnatic, are decomposed by hydrochloric acid, with separation of gelatinous silica.

Obs.—Occurs in some diorites; occasionally in connection with gabbro and serpentine rocks; in some cases along with corundum; in many volcanic rocks, andesites, basalts, etc.; as a constituent of some meteorites (Juvenas, Stannern).

Anorthite (*christianite* and *biotine*) occurs at Mount Vesuvius in isolated blocks among the old lavas in the ravines of Monte Somma; in the Albani Mts.; on the Pesmeda Alp, Monzoni, Tyrol, as a contact mineral; Aranyer Berg, Transylvania, in andesite; on Iceland; near Bogoslovsk in the Ural. In the Cyclopean Islands (*cyclopite*). In the lava of the island of Miyake, Japan.

Anorthite was named in 1823 by Rose from *ανορθός*, *oblique*, the crystallization being triclinic.

Celsian. $BaAl_2Si_2O_8$, similar to anorthite, but containing barium instead of calcium. Massive, with the usual cleavages *c* (001) and *b* (010), *cb* = 89° 36′. H. = 6–6·5. G. = 3·37. Colorless. Extinction: on *c*, 3° 10′; on *b*, 26° 45′. From Jakobsberg, Sweden.

II. Metasilicates. $RSiO_3$.

Salts of Metasilicic Acid, H_2SiO_3; characterized by an oxygen ratio of 2 : 1 for silicon to bases. The Division closes with a number of species, in part of somewhat doubtful composition, forming a transition to the Orthosilicates.

The metasilicates include two prominent and well-characterized groups, viz., the Pyroxene Group and the Amphibole Group. There are also others less important.

Leucite Group. Isometric.

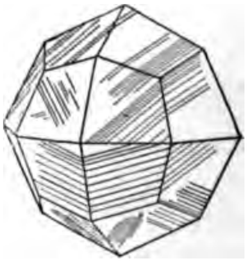
In several respects leucite is allied to the species of the FELDSPAR GROUP, which immediately precede.

Leucite	$KAl(SiO_3)_2$	Isometric at 500°
	Pseudo-isometric at ordinary temperatures.	
Pollucite	$H_2Cs_4Al_4(SiO_3)_9$	Isometric

LEUCITE. Amphigène.

Isometric at 500° C.; pseudo-isometric under ordinary conditions (see p. 230). Commonly in crystals varying in angle but little from the tetragonal trisoctahedron *n* (211), sometimes with *a* (100), and *d* (110) as subordinate forms. Faces often showing fine striations due to twinning (Fig. 749). Also in disseminated grains; rarely massive granular.

749.



Cleavage: *d* (110) very imperfect. Fracture conchoidal. Brittle. H. = 5·5–6. G. = 2·45–2·50. Luster vitreous. Color white, ash-gray or smoke-gray. Streak uncolored. Translucent to opaque. Usually shows very feeble double refraction: $\omega = 1\cdot508$, $\epsilon = 1\cdot509$ (p. 230).

Comp. — $KAl(SiO_3)_2$ or $K_2O.Al_2O_3.4SiO_2$ = Silica 55·0, alumina 23·5, potash 21·5 = 100.

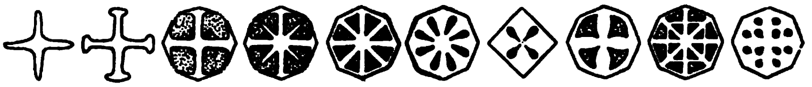
Soda is present only in small quantities, unless as introduced by alteration; traces of lithium, also of rubidium and cæsium, have been detected.

Pyr., etc.—B.B. infusible; with cobalt solution gives a blue color (aluminium). Decomposed by hydrochloric acid without gelatinization.

Diff.—Characterized by its trapezohedral form, absence of color, and infusibility. It is softer than garnet and harder than analcite; the latter yields water and fuses.

Recognized in thin sections by its extremely low refraction, isotropic character, and the symmetrical arrangement of inclusions (Fig. 750; also Fig. 471, p. 141). Larger crystals

750.



Leucite crystals from the leucitite of the Bearpaw Mts., Montana (Pirsson). These show the progressive growth from skeleton forms to complete crystals with glass inclusions.

are commonly not wholly isotropic and, further, show complicated systems of twinning-lines (Fig. 749); the birefringence is, however, very low, and the colors scarcely rise above dark gray; they are best seen by introduction of the quartz or selenite plate yielding red of the first order. The smaller leucites, which lack this twinning or the inclusions, are only to be distinguished from sodalite or analcite by chemical tests.

Obs.—Leucite occurs only in igneous rocks, and especially in recent lavas, as one of the products of crystallization of magmas rich in potash and low in silica (for which reason this species rather than orthoclase is formed). The larger embedded crystals are commonly anisotropic and show twinning lamellæ; the smaller ones, forming the groundmass, are isotropic and without twinning. Found in leucitites and leucite-basalts, leucitophyres, leucite-phonolites and leucite-tephrites; also in certain rocks occurring in dikes. Very rare in intruded igneous rocks, only one or two instances being known; but its former presence under such conditions is indicated by pseudomorphs, often of large size (*pseudoleucite*) consisting of nephelite and orthoclase, also of analcite.

The prominent localities are, first of all, Vesuvius and Mte. Somma, where it is thickly disseminated through the lava in grains, and in large perfect crystals; also in ejected masses; also near Rome, at Capo di Bove, Rocca Monfina, etc. Further in leucite-tephrite at Proceno near Lake Bolsena in central Italy; also about the Laacher See and at several points in the Eifel; at Rieden near Andernach; at Meiches in the Vogelsgebirge; in the Kaiserstuhlgebirge. Occurs in Brazil, at Pinhalzinho. From the Cerro de las Virgines, Lower California. In the United States it is present in a rock in the Green River Basin at the Leucite Hills, Wyoming; also in the Absaroka range, in northwestern Wyoming; in the Highwood and Bearpaw Mts., Montana (in part pseudoleucite). On the shores of Vancouver Island, where magnificent groups of crystals have been found as drift boulders.

Pseudoleucite (see above) occurs in the phonolite (tinguaite) of the Serra de Tingua, Brazil; at Magnet Cove, Arkansas; near Hamburg, N. J.; Montana; also in the Cariboo Distr., British Columbia.

Named from λευκός, *white*, in allusion to its color.

Pollucite. **Essentially $H_2O.2Cs_2O.2Al_2O_3.9SiO_2$. Isometric; often in cubes; also massive. H. = 6·5. G. = 2·901. Colorless. Occurs very sparingly in the island of Elba; with petalite (castorite); also at Hebron and Rumford, Me.**

Pyroxene Group.

Orthorhombic, Monoclinic, Triclinic.

Composition for the most part that of a metasilicate, $RSiO_3$, with $R =$ Ca,Mg,Fe chiefly, also Mn,Zn. Further $RSiO_3$ with $\overset{\text{II}}{R}(Fe,Al)_2SiO_6$, less often containing alkalies (Na,K), and then $RSiO_3$ with $\overset{\text{I}}{R}Al(SiO_3)_2$. Rarely including zirconium and titanium, also fluorine.

a. Orthorhombic Section.

		$\breve{a} : \bar{b} : \dot{c}$	or	$\bar{b} : \breve{a} : \dot{c}$
Enstatite	$MgSiO_3$	0·9702 : 1 : 0·5710		1·0307 : 1 : 0·5885
Bronzite	$(Mg,Fe)SiO_3$			
Hypersthene	$(Fe,Mg)SiO_3$	0·9713 : 1 : 0·5704		1·0319 : 1 : 0·5872

The second set of axial ratios, with $\breve{a} = 1$, brings out the similarity of the form to the monoclinic species.

β. *Monoclinic Section.*

		$\grave{a} : \bar{b} : \acute{c}$	β
Pyroxene		1·0921 : 1 : 0·5893	74° 10′

I. *Non-aluminous Varieties:*

1. Diopside	$CaMg(SiO_3)_2$ $Ca(Mg,Fe)(SiO_3)_2$
Malacolite, Salite, Diallage, etc.	
2. Hedenbergite	$CaFe(SiO_3)_2$
Manganhedenbergite	$Ca(Fe,Mn)(SiO_3)_2$
3. Schefferite	$(Ca,Mg)(Fe,Mn)(SiO_3)_2$
Jeffersonite	$(Ca,Mg)(Fe,Mn,Zn)(SiO_3)_2$

II. *Aluminous Varieties:*

4. Augite	$Ca(Mg,Fe)(SiO_3)_2$ with $(Mg,Fe)(Al,Fe)_2SiO_6$
Leucaugite, Fassaite, Augite, Ægirite-augite.	

		$\grave{a} : \bar{b} : \acute{c}$	β
Acmite (Ægirite)	$Na\overset{\text{III}}{Fe}(SiO_3)_2$	1·0996 : 1 : 0·6012	73° 11′
Spodumene	$LiAl(SiO_3)_2$	1·1238 : 1 : 0·6355	69° 40′
Jadeite	$NaAl(SiO_3)_2$	1·103 : 1 : 0·613	72° 44½′

		$\grave{a} : \bar{b} : \acute{c}$	β
Wollastonite	$CaSiO_3$	1·0531 : 1 : 0·9676	84° 30′
Pectolite	$HNaCa_2(SiO_3)_3$	1·1140 : 1 : 0·9864	84° 40′

γ. *Triclinic Section.*

		$\bar{a} : \breve{b} : \acute{c}$	α	β	γ
Rhodonite	$MnSiO_3$	1·0729 : 1 : 0·6213	103° 18′	108° 44′	81° 39′
also	$(Mn,Ca)SiO_3$ $(Mn,Fe)SiO_3$ $(Mn,Zn,Fe,Ca)SiO_3$				
Babingtonite	$(Ca,Fe,Mn)SiO_3.Fe_2(SiO_3)_3$	1·0691 : 1 : 0·6308	104° 21½′	108° 31′	83° 34′

The rare species Rosenbuschite, Låvenite, Wöhlerite also belong under the monoclinic section and Hiortdahlite under the triclinic section of this group.

The Pyroxene Group embraces a number of species which, while falling in different systems—orthorhombic, monoclinic, and triclinic—are yet closely related in form. Thus all have a fundamental prism with an angle of 93° and 87°, parallel to which there is more or less distinct cleavage. Further, the angles in other prominent zones show a considerable degree of similarity. In composition the metasilicates of calcium, magnesium, and ferrous iron are most prominent, while compounds of the form $\overset{\text{II}}{R}(Al,\overset{\text{III}}{Fe})_2SiO_6$, $\overset{\text{I}}{R}Al(SiO_3)_2$ are also important.

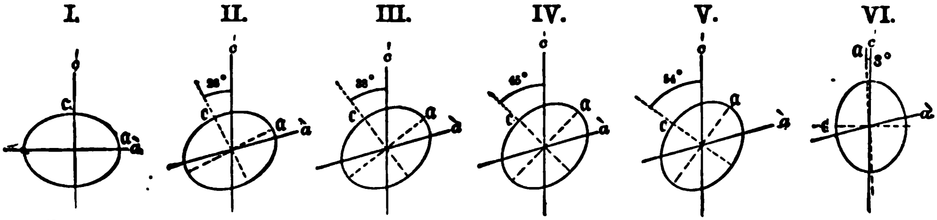
The species of the pyroxene group are closely related in composition to the corresponding species of the amphibole group, which also embraces members in the orthorhombic, monoclinic, and triclinic systems. In a number of cases the same chemical compound appears in each group; furthermore, a change by paramorphism of pyroxene to amphibole is often observed. In form also the two groups are related, as shown in the axial ratio; also in the parallel growth of crystals of monoclinic amphibole upon or about those of pyroxene (Fig. 430, p. 131). The axial ratios for the typical monoclinic species are:

Pyroxene $\grave{a} : \bar{b} : \dot{c} = 1{\cdot}0921 : 1 : 0{\cdot}5893$ $\beta = 74° 10'$
Amphibole $\grave{a} : \frac{1}{2}\bar{b} : \dot{c} = 1{\cdot}1022 : 1 : 0{\cdot}5875$ $\beta = 73° 58'$

See further on p. 398.

The optical relations of the prominent members of the Pyroxene Group, especially as regards the connection between the position of the ether-axes and the crystallographic axes are exemplified in the following figures (Cross).

751.



I, Enstatite, etc. II, Spodumene. III, Diopside, etc. IV, Hedenbergite, Augite. V, Augite. VI, Ægirite.

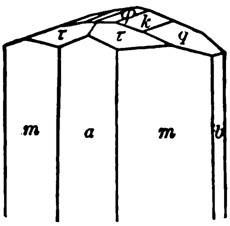
A corresponding exhibition of the prominent amphiboles is given under that group, Fig. 785, p. 398.

α. Orthorhombic Section.

ENSTATITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}9702 : 1 : 0{\cdot}5710$.

752.



Bamle.

mm''', 110 ∧ 1$\bar{1}$0 = 88° 16'. *ττ'*, 223 ∧ $\bar{2}$23 = 40° 16½.
qq', 023 ∧ 0$\bar{2}$3 = 41° 41'. *ττ'''*, 223 ∧ 2$\bar{2}$3 = 39° 1½.

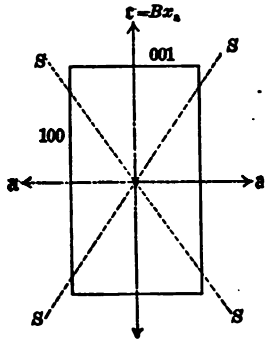
Twins rare: tw. pl. *h* (014) as twinning lamellæ; also tw. pl. (101) as stellate twins crossing at angles of nearly 60°, sometimes six-rayed. Distinct crystals rare, habit prismatic. Usually massive, fibrous, or lamellar.

Cleavage: *m* rather easy. Parting ‖ *b*; also *a*. Fracture uneven. Brittle. H. = 5·5. G. = 3·1–3·3. Luster a little pearly on cleavage-surfaces to vitreous; often metalloidal in the bronzite variety. Color grayish, yellowish or greenish white, to olive-green and brown. Streak uncolored, grayish. Translucent to nearly opaque. Pleochroism weak, more marked in varieties relatively rich in iron. Optically +. Ax.-pl. ‖ *b*. Bx ⊥ *c*. Dispersion $\rho < v$ weak. Axial angle large and variable, increasing with the amount of iron, usually about 90° for FeO = 10 p. c. $\beta_y = 1{\cdot}669$; $\gamma - \alpha = 0{\cdot}009$.

Comp., Var.—$MgSiO_3$ or $MgO.SiO_2$ = Silica 60, magnesia 40 = 100. Also $(Mg,Fe)SiO_3$ with Mg : Fe = 8 : 1, 6 : 1, 3 : 1, etc.

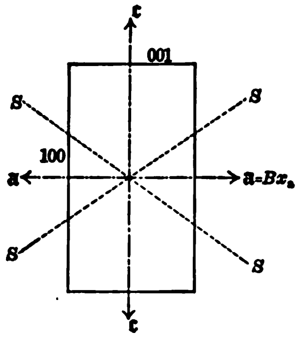
Var.—1. *With little or no iron; Enstatite.* Color white, yellowish, grayish, or greenish white; luster vitreous to pearly; G. = 3·10–3·13. *Chladnite* (Shepardite of Rose), which makes up 90 p. c. of the Bishopville meteorite, belongs here and is the purest kind. *Victorite*, occurring in the Deesa meteoric iron in rosettes of acicular crystals, is similar.

753.



Enstatite (Bronzite).

754.



Hypersthene.

2. ***Ferriferous; Bronzite.*** Color grayish green to olive-green and brown. Luster of cleavage-surface often adamantine-pearly to submetallic or bronze-like; this, however, is usually of secondary origin and is not essential. With the increase of iron (above 12 to 14 p. c.) bronzite passes to hypersthene, the optic axial angle changing so that in the latter $\mathfrak{a} = Bx_a$ and $Bx_a \perp \mathfrak{a}$. This is illustrated by Figs. 753, 754.

755.

756.

757.

Figs. 755, Bronzite enclosing laminæ of diallage (P) 756. Diallage (P) enclosing laminæ of bronzite (E). From Lacroix. 757, Enstatite Chondrule from the Knyahinya Meteorite.

Pyr., etc.—B.B. almost infusible, being only slightly rounded on the thin edges; F. = 6. Insoluble in hydrochloric acid.

Obs.—Enstatite (incl. bronzite) is a common constituent of peridotites and the serpentines derived from them; it also occurs in crystalline schists. It is often associated in parallel growth with a monoclinic pyroxene, *e.g.*, diallage (Figs. 755, 756). A common mineral in meteoric stones often occurring in chondrules with eccentric radiated structure (Fig. 757).

Occurs near Aloysthal in Moravia, in serpentine; at Kupferberg in Bavaria; at Baste in the Harz (*protobastite*); in the so-called olivine bombs of the Dreiser Weiher in the Eifel; in immense crystals, in part altered, at the apatite deposits of Kjörrestad near Bamle, Norway; in the peridotite associated with the diamond deposits of South Africa.

In the U. S., in New York at the Tilly Foster magnetite mine, Brewster, Putnam Co., with chondrodite; at Edwards, N. Y.

Named from ἐνστάτης, an *opponent*, because so refractory. The name *bronzite* has priority, but a bronze luster is not essential, and is far from universal.

HYPERSTHENE.

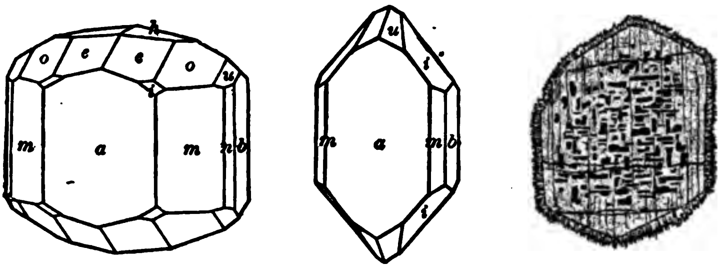
Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}9713 : 1 : 0{\cdot}5704$.

mm''', $110 \wedge 1\bar{1}0 = 88° 20'$. *oo'''*, $111 \wedge 1\bar{1}1 = 52° 28'$.
hh', $014 \wedge 0\bar{1}4 = 16° 14'$. *uu'''*, $232 \wedge 2\bar{3}2 = 72° 50'$.

Crystals rare, habit prismatic, often tabular ‖ *a*, less often ‖ *b*. Usually foliated massive; sometimes in embedded spherical forms.

Cleavage: *b* perfect; *m* and *a* distinct but interrupted. Fracture uneven. Brittle. H. = 5–6. G. = 3·40–3·50. Luster somewhat pearly on a cleavage-surface, and sometimes metalloidal. Color dark brownish green, grayish black, greenish black, pinchbeck-brown. Streak grayish, brownish gray. Translucent to nearly opaque. Pleochroism often strong, especially in the kinds with high iron percentage; thus ‖ a or ă brownish red, b or b̆ reddish yellow, c or ć green. Optically −. Ax. pl. ‖ *b*. Bx $\perp$ *a*. Dispersion $\rho > v$. Axial angle rather large and variable, diminishing with increase of iron, cf. enstatite, p. 384, and Figs. 753, 754, p. 385. $\beta = 1{\cdot}702$; $\gamma - \alpha = 0{\cdot}013$.

758. 759. 760.



Figs. 758, *Amblystegite*, Laach. 759, Málnás. 760, Section ‖ *b* (010) showing inclusions (× 3); the exterior transformed to actinolite; from Lacroix.

Hypersthene often encloses minute tabular scales, usually of a brown color, arranged mostly parallel to the basal plane (Fig. 760), also less frequently vertical or inclined 80° to *ć*; they may be brookite (göthite, hematite), but their true nature is doubtful. They are the cause of the peculiar metalloidal luster or schiller, and are often of secondary origin, being developed along the so-called "solution-planes" (p. 149).

Comp., Var.—$(Fe,Mg)SiO_3$, with Fe : Mg = 1 : 3(FeO = 16·7 p. c.), 1 : 2(FeO = 21·7 p. c.) to nearly 1 : 1(FeO = 31·0 p. c.). Alumina is sometimes present (up to 10 p. c.) and the composition then approximates to the aluminous pyroxenes.

Of the orthorhombic magnesium-iron metasilicates, those with FeO > 12 to 15 p. c. are usually to be classed with hypersthene, which is further characterized by being optically negative and having dispersion $\rho > v$.

Pyr., etc.—B.B. fuses to a black enamel, and on charcoal yields a magnetic mass; fuses more easily with increasing amount of iron. Partially decomposed by hydrochloric acid.

Obs.—Hypersthene, associated with a triclinic feldspar (labradorite), is common in certain granular eruptive rocks, as norite, hyperite, gabbro, also in some andesites (*hypersthene-andesite*), a rock recently shown to occur rather extensively in widely separated regions.

It occurs at Isle St. Paul; Labrador; in Greenland; at Farsund and elsewhere in Norway; Elfdalen in Sweden; Penig in Saxony; Ronsberg in Bohemia; the Tyrol; Neurode in Silesia; Bodenmais, Bavaria. *Amblystegite* is from the Laacher See. *Szaboite* occurs with pseudobrookite and tridymite, in cavities in the andesite of the Aranyer Berg, Transylvania, and elsewhere.

Occurs in the norites of the Cortlandt region on the Hudson river, N. Y.; also common with labradorite in the Adirondack Archæan region of northern New York and northward in Canada. In the hypersthene-andesites of Mt. Shasta, California; Buffalo Peaks, Colorado and other points.

Hypersthene is named from ὑπέρ and σθένος, *very strong*, or *tough*.

BASTITE, or SCHILLER SPAR. An altered enstatite (or bronzite) having approximately the composition of serpentine. It occurs in foliated form in certain granular eruptive rocks and is characterized by a bronze-like metalloidal luster or schiller on the chief cleavage-face (*b*), which "schillerization" (p. 190) is of secondary origin. H. = 3·5–4. G. = 2·5–2·7. Color leek-green to olive- and pistachio-green, and pinchbeck-brown. Pleochroism not marked. Optically −. Double refraction weak. Ax. pl. | *a* (hence normal to that of enstatite). Bx ⊥ *b*. Dispersion $\rho > v$. The original bastite was from Baste near Harzburg in the Harz; also from Todtmoos in the Schwarzwald.

Peckhamite, $2(Mg,Fe)SiO_3.(Mg,Fe)SiO_4$. Occurs in rounded nodules in the meteorite of Estherville, Emmet Co., Iowa, May 10, 1879. G. = 3·23. Color light greenish yellow.

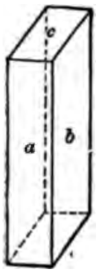
β. *Monoclinic Section.*

PYROXENE.

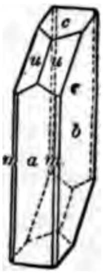
Monoclinic. Axes $\grave{a} : \breve{b} : \grave{c} = 1·0921 : 1 : 0·5893$; $\beta = 74° 10'$.

mm''',	$110 \wedge 1\bar{1}0 = 92° 50'$.	*cv*,	$001 \wedge 221 = 49° 54'$.
ca,	$001 \wedge 100 = 74° 10'$.	*cm*,	$001 \wedge 110 = 79° 9\frac{1}{2}'$.
cp,	$001 \wedge \bar{1}01 = 31° 20'$.	*cs*,	$001 \wedge \bar{1}11 = 42° 2'$.
ee',	$011 \wedge 0\bar{1}1 = 59° 6'$.	*uu'*,	$111 \wedge 1\bar{1}1 = 48° 29'$.
zz',	$021 \wedge 0\bar{2}1 = 97° 11'$.	*ss'*,	$\bar{1}11 \wedge \bar{1}\bar{1}1 = 59° 11'$.
cu,	$001 \wedge 111 = 33° 49\frac{1}{2}'$.	*oo'*,	$\bar{2}21 \wedge \bar{2}\bar{2}1 = 84° 11'$.

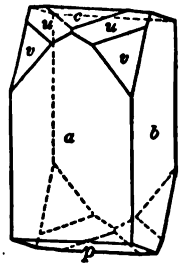
761.



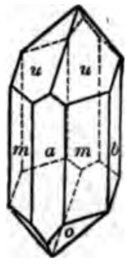
762.



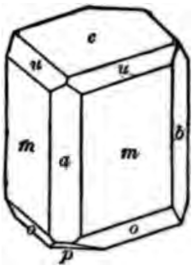
763.



764.

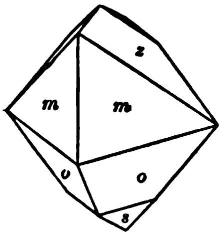


765.

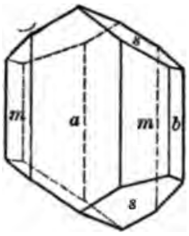


Twins: tw. pl. (1) *a*, contact-twins, common (Fig. 769), sometimes polysynthetic. (2) *c*, as twinning lamellæ producing striations on the vertical faces and pseudo-cleavage or parting ∥ *c* (Fig. 770); very common, often secondary. (3) *y* (101) cruciform-twins, not common (Fig. 421, p. 130). (4) *W* $(\bar{1}22)$ the vertical axes crossing at angles of nearly 60°; sometimes repeated as a six-rayed star (Fig. 420, p. 130). Crystals usually prismatic in habit, often short and thick, and either a square prism (*a*, *b* prominent), or nearly square (93°, 87°) with *m* predominating; sometimes a nearly symmetrical 8-sided prism with *a*, *b*, *m* (Fig. 770). Often coarsely lamellar, ∥ *c* or *a*. Also granular, coarse or fine; rarely fibrous or columnar.

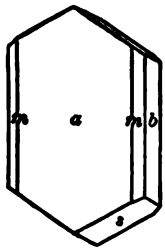
766.



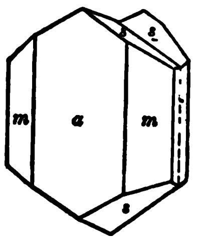
767.



768.

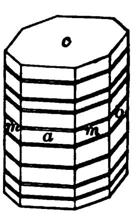


769.

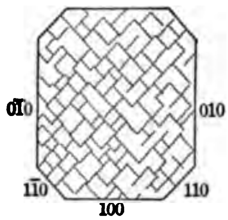


Cleavage: *m* sometimes rather perfect, but interrupted, often only observed in thin sections ⊥ $\dot{c}$ (Fig. 771). Parting ∥ c, due to twinning, often prominent, especially in large crystals and lamellar masses (Fig. 770); also ∥ a less distinct and not so common. Fracture uneven to conchoidal. Brittle. H. = 5–6. G. = 3·2–3·6, varying with the composition. Luster vitreous inclining to resinous; often dull; sometimes pearly ∥ c in kinds showing parting. Color usually green of various dull shades, varying from nearly colorless, white, or grayish white to brown and black; rarely bright green, as in kinds containing chromium; also blue. Streak white to gray and grayish green. Transparent to opaque. Pleochroism usually weak, even in dark-colored varieties; sometimes marked, especially in violet-brown kinds containing titanium.

770.



771.

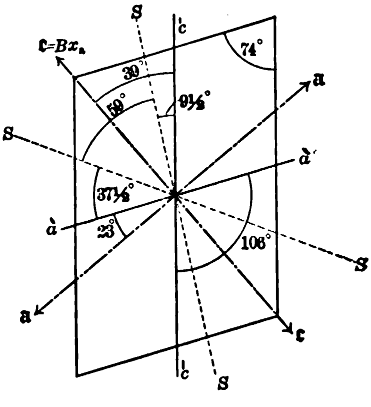


Optically +. Birefringence strong, $(\gamma - \alpha) = 0{\cdot}02 - 0{\cdot}03$. Ax. pl. ∥ b. $Bx_a \wedge \dot{c} = \mathfrak{c} \wedge \dot{c} = +36°$ in diopside, to $+52°$ in augite (wh. see), or $\mathfrak{c}c = 20°$ to 36°, the angle in general increasing with amount of iron. For diopside from Ala (Dx.): $2E_y = 111° \ 20'$. Also (Flink) for white diopside from Nordmark (2·49 p. c. FeO):

$Bx_a \wedge \dot{c}$	$2V_r$	$2V_y$	$2V_{gr}$	β_r	β_y	β_{gr}
+ 38° 3½′	59° 9′	58° 52′	58° 40′	1·68978	1·69359	1·69869

Comp., Var.—For the most part a normal metasilicate, $RSiO_3$, chiefly of calcium and magnesium, also iron, less often manganese and zinc. The alkali metals potassium and sodium present rarely, except in very small amount. Also in certain varieties containing the trivalent metals aluminium, ferric iron, and manganese. These last varieties may be most simply considered as molecular compounds of $Ca(Mg,Fe)Si_2O_6$ and $(Mg,Fe)(Al,Fe)_2SiO_6$, as suggested by Tschermak. Chromium is sometimes present in small amount; also titanium replacing silicon.

772.



The name *Pyroxene* is from πῦρ, *fire*, and ξένος, *stranger*, and records Haüy's idea that the mineral was, as he expresses it, "a stranger in the domain of fire," whereas, in fact, it is, next to the feldspars, the most universal constituent of igneous rocks.

The varieties are numerous and depend upon variations in composition chiefly; the more prominent of the varieties properly rank as sub-species.

I. *Containing little or no Aluminium.*

1. Diopside. Malacolite, Alalite. *Calcium-magnesium pyroxene.* Formula $CaMg(SiO_3)_2$ = Silica 55·6, lime 25·9, magnesia 18·5 = 100. Color white, yellowish, grayish white to pale green, and finally to dark green and nearly black; sometimes transparent and colorless, also rarely a fine blue. In pris-

matic crystals, often slender; also granular and columnar to lamellar massive. G. = 3·2–3·38. $Bx_a \wedge \dot{c} = +36^\circ$ and upwards. $\gamma - \alpha = 0{\cdot}03$. Iron is present usually in small amount as noted below, and the amount increases as it graduates toward true hedenbergite.

The following belong here: *Chrome-diopside*, contains chromium (1 to 2·8 p. c. Cr_2O_3), often a bright green.

Malacolite, as originally described, was a pale-colored translucent variety from Sala, Sweden.

Alalite occurs in broad right-angled prisms, colorless to faint greenish or clear green, from the Mussa Alp in the Ala valley, Piedmont.

Traversellite, from Traversella, is similar.

Violan is a fine blue diopside from St. Marcel, Piedmont, Italy; occurring in prismatic crystals and massive.

Canaanite is a grayish-white or bluish-white pyroxene rock occurring with dolomite at Canaan, Conn.

Lavrovite is a pyroxene, colored green by vanadium, from the neighborhood of Lake Baikal, in eastern Siberia.

Diopside is named from δίς, *twice* or *double*, and ὄψις, *appearance*. *Malacolite* is from μαλακός, *soft*, because softer than feldspar, with which it was associated.

2. HEDENBERGITE. *Calcium-iron pyroxene.* Formula $CaFe(SiO_3)_2$ = Silica 48·4, iron protoxide 29·4, lime 22·2 = 100. Color black. In crystals, and also lamellar massive. G. = 3·5–3·58. $Bx_a \wedge \dot{c} = +48^\circ$. Manganese is present in *manganhedenbergite* to 6·5 p. c. Color grayish green. G. = 3·55.

Between the two extremes, diopside and hedenbergite, there are numerous transitions conforming to the formula $Ca(Mg,Fe)Si_2O_6$. As the amount of iron increases the color changes from light to dark green to nearly black, the specific gravity increases from 3·2 to 3·6, and the angle $Bx_a \wedge \dot{c}$ also from 36° to 48°.

The following are varieties, coming under these two sub-species, based in part upon structure, in part on peculiarities of composition.

Salite (Sahlite), color grayish green to deep green and black; sometimes grayish and yellowish white; in crystals; also lamellar (parting ∥ c) and granular massive; from Sala in Sweden. *Baikalite*, a dark dingy green variety, in crystals, with parting ∥ c; from Lake Baikal, in Siberia.

Coccolite is a granular variety, embedded in calcite, also forming loosely coherent to compact aggregates; color varying from white to pale green to dark green, and then containing considerable iron; the latter the original coccolite. Named from κόκκος, a *grain*.

DIALLAGE. A lamellar or thin-foliated pyroxene, characterized by a fine lamellar structure and parting ∥ a, with also parting ∥ b, and less often ∥ c. Also a fibrous structure ∥ $\dot{c}$. Twinning ∥ a, often polysynthetic; interlamination with an orthorhombic pyroxene common (Figs. 755 and 756, p. 386). Color grayish green to bright grass-green, and deep green; also brown. Luster of surface a often pearly, sometimes metalloidal or exhibiting schiller and resembling bronzite, from the presence of microscopic inclusions of secondary origin. $Bx_a \wedge \dot{c} = +39$ to 40°; $\beta = 1{\cdot}681$; $\gamma - \alpha = 0{\cdot}024$. H. = 4; G. = 3·2–3·35. In composition near diopside, but often containing alumina and sometimes in considerable amount, then properly to be classed with the augites. Often changed to amphibole, see smaragdite, p. 401, and uralite, p. 401. Named from διαλλαγή, *difference*, in allusion to the dissimilar planes of fracture. This is the characteristic pyroxene of gabbro, and other related rocks.

Omphacite. The granular to foliated pyroxenic constituent of the garnet-rock called eclogite, often interlaminated with amphibole (smaragdite); color grass-green. Contains some Al_2O_3.

3. SCHEFFERITE. A manganese pyroxene, sometimes also containing much iron. Color brown to black.

In crystals, sometimes tabular ∥ c, also with p ($\bar{1}01$) prominent, more often elongated in the direction of the zone $b : p$ (101), rarely prismatic, ∥ $\dot{c}$. Twins, with a as tw. pl. very common. Also crystalline, massive. Cleavage prismatic, very distinct. Color yellowish brown to reddish brown; also black (*iron-schefferite*). Optically +. $Bx_a \wedge \dot{c} = \mathfrak{c} \wedge \dot{c} = 44^\circ\ 25\frac{1}{2}'$. The iron-schefferite from Pajsberg is black in color and has $\mathfrak{c} \wedge \dot{c} = +49^\circ$ to 59° for different zones in the same crystal. The brown iron-schefferite (*urbanite*) from Långban has $\mathfrak{c} \wedge \dot{c} = 69^\circ\ 8'$. It resembles garnet in appearance.

Jeffersonite is a manganese-zinc pyroxene from Franklin Furnace, N. J. (but the zinc may be due to impurity). In large, coarse crystals with edges rounded and faces uneven. Color greenish black, on the exposed surface chocolate-brown.

II. *Aluminous.*

4. AUGITE. *Aluminous pyroxene.* Composition chiefly $CaMgSi_2O_6$ with $(Mg,Fe)(Al,Fe)_2SiO_6$, and occasionally also containing alkalies and then graduating toward ægirite. Titanium is also sometimes present. Here belong:

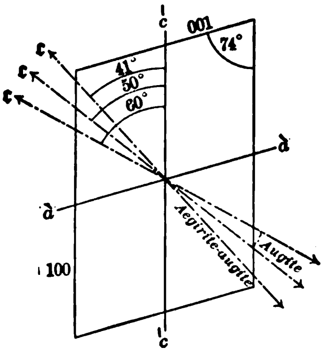
a. **LEUCAUGITE.** Color white or grayish. Contains alumina, with lime and magnesia, and little or no iron. Looks like diopside. H. = 6·5; G. = 3·19. Named from λευκός, *white.*

b. **FASSAITE.** Includes the pale to dark, sometimes deep-green crystals, or pistachio-green and then resembling epidote (Fig. 766). The aluminous kinds of diallage also belong here. Named from the locality in the Fassathal, Tyrol. *Pyrgom* is from πύργωμα, *a tower.*

c. **AUGITE.** Includes the greenish or brownish black and black kinds, occurring mostly in eruptive rocks. It is usually in short prismatic crystals, thick and stout, or tabular ‖ *a*; often twins (Figs. 767–769). Ferric iron is here present, in relatively large amount, and the angle $Bx_a \wedge \dot{c}$ becomes + 50° to 52°. $\beta = 1·717$; $\gamma - \alpha = 0·022$. TiO_2 is present in some kinds, which are then pleochroic. Named from αυγή, *luster.*

d. **ALKALI-AUGITE.** Here belong varieties of augite characterized by the presence of alkalies, especially soda; they approximate in composition and optically to acmite and ægirite ($Bx_a \wedge \dot{c} = 60°$, Fig. 773), and are sometimes called ægirite-augite (cf. Fig. 776, p. 392). Known chiefly from rocks rich in alkalies, as elæolite-syenite, phonolite, leucitite, etc.

773.



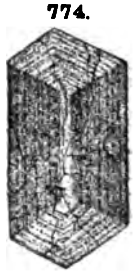
Pyr., etc.—Varying widely, owing to the wide variations in composition in the different varieties, and often by insensible gradations. Fusibility, 3·75 in diopside; 3·5 in salite, baikalite, and omphacite; 3 in jeffersonite and augite; 2·5 in hedenbergite. Varieties rich in iron afford a magnetic globule when fused on charcoal, and in general the fusibility varies with the amount of iron. Many varieties give with the fluxes reactions for manganese. Most varieties are unacted upon by acids.

Diff.—Characterized by monoclinic crystallization and the prismatic angle of 87° and 93°, hence yielding nearly square prisms; these may be mistaken for scapolite if terminal faces are wanting or indistinct (but scapolite fuses easily B.B. with intumescence). The oblique parting (‖ *c*, Fig. 770) often distinctive, also the common dull green to gray and brown colors. Amphibole differs in prismatic angle (55½° and 124½°) and cleavage, and in having common columnar to fibrous varieties, which are rare with pyroxene. See also p. 398.

The common rock-forming pyroxenes are distinguished in thin sections by their high relief; usually greenish to olive tones of color; distinct system of interrupted cleavage-cracks crossing one another at nearly right angles in sections ⊥ $\dot{c}$ (Fig. 771); high interference-colors; general lack of pleochroism; large extinction-angle, 35° to 50° and higher, for sections ‖ *b* (010). The last-named sections are easily recognized by showing the highest interference-colors; yielding no optical figures in convergent light and having parallel cleavage-cracks, the latter in the direction of the vertical axis. See also ægirite, p. 392.

A zonal banding is common, the successive laminæ sometimes differing in extinction-angle and pleochroism; also the hour-glass structure occasionally distinct (Fig. 774, from Lacroix).

774.



Obs.—Pyroxene is a common mineral in crystalline limestone and dolomite, in serpentine and in volcanic rocks; and occurs also, but less abundantly, in connection with granitic rocks and metamorphic schists; sometimes forms large beds or veins, especially in Archæan rocks. It occurs also in meteorites. The pyroxene of limestone is mostly white and light green or gray in color, falling under *diopside* (malacolite, salite, coccolite); that of most other metamorphic rocks is sometimes white or colorless, but usually green of different shades, from pale green to greenish black, and occasionally black; that of serpentine is sometimes in fine crystals, but often of the foliated green kind called *diallage;* that of eruptive rocks is usually the black to greenish-black *augite.*

In limestone the associations are often amphibole, scapolite, vesuvianite, garnet, orthoclase, titanite, apatite, phlogopite, and sometimes brown tourmaline, chlorite, talc, zircon, spinel, rutile, etc.; and in other metamorphic rocks mostly the same. In eruptive rocks it may be in distinct embedded crystals, or in grains without external crystalline form; it often occurs with similarly disseminated chrysolite (olivine), crystals of orthoclase (sanidine), labradorite, leucite, etc.; also with a rhombic pyroxene, amphibole, etc.

Pyroxene, as an essential rock-making mineral, is especially common in basic eruptive rocks. Thus, as augite, with a triclinic feldspar (usually labradorite), magnetite, often chrysolite, in basalt, basaltic lavas and diabase; in andesite; also in trachyte; in peridotite and pikrite; with nephelite in phonolite. Further with elæolite, orthoclase, etc., in elæolite-syenite and augite-syenite; also as diallage in gabbro; in many peridotites and the serpentines formed from them; as diopside (malacolite) in crystalline schists. In limburgite, augitite and pyroxenite, pyroxene is present as the prominent constituent, while feldspar is absent; it may also form rock masses alone nearly free from associated minerals.

Diopside (alalite, mussite) occurs in fine crystals on the Mussa alp in the Ala valley in Piedmont, associated with garnets (hessonite) and talc in veins traversing serpentine; in fine crystals at Traversella; at Zermatt in Switzerland; Schwarzenstein in the Zillerthal; Ober-Sulzbachthal and elsewhere in Tyrol and in the Salzburg Alps; Reichenstein; Rezbánya, Hungary; Achmatovsk in the Ural with almandite, clinochlore; L. Baikal (*baikalite*) in eastern Siberia; Pargas in Finland; at Nordmark, Sweden.

Hedenbergite is from Tunaberg, Sweden; Arendal, Norway. Manganhedenbergite from Vester Silfberg; *schefferite* from Långban, Sweden.

Augite (incl. fassaite) occurs on the Pesmeda alp, Mt. Monzoni, and elsewhere in the Fassathal, as a contact formation; Traversella, Piedmont; the Laacher See and the Eifel; Sasbach in the Kaiserstuhl; Vesuvius, white rare, green, brown, yellow to black; Frascati; Etna; the Azores and Cape Verde Islands; the Sandwich Islands, and many other regions of volcanic rocks.

In N. America, occurs in *Maine*, at Raymond and Rumford, diopside, salite, etc. In *Vermont*, at Thetford, black augite, with chrysolite, in bowlders of basalt. In *Conn.*, at Canaan, white cryst., often externally changed to tremolite, in dolomite; also the pyroxenic rock called *canaanite*. In *N. York*, at Warwick, fine cryst.; in Westchester Co., white, at the Sing Sing quarries; in Orange Co., in Monroe, at Two Ponds, cryst., often large, in limestone; near Greenwood furnace, and also near Edenville; in Lewis Co., at Diana, white and black cryst.; in St. Lawrence Co., at Fine, in large cryst.; at De Kalb, fine diopside; also at Gouverneur, Rossie, Russell, Pitcairn; at Moriah, coccolite, in limestone. In *N. Jersey*, Franklin Furnace, Sussex Co., good cryst., also *jeffersonite*. In *Penn.*, near Attleboro', cryst. and granular; in Pennsbury, at Burnett's quarry, diopside; at the French Creek mines, Chester Co., chiefly altered to fibrous amphibole. In *Tennessee*, at the Ducktown mines.

In *Canada*, at Calumet I., grayish-green cryst. in limestone; in Bathurst, colorless or white cryst.; at Grenville, dark green cryst., and granular; Burgess, Lanark Co.; Renfrew Co., with apatite, titanite, etc.; Orford, Sherbrooke Co., white crystals, also of a chrome-green color with chrome garnet; at Hull and Wakefield, white crystals with nearly colorless garnets, honey-yellow vesuvianite, etc. At many other points in the Archæan of Quebec and Ontario, especially in connection with the apatite deposits.

Pyroxene undergoes alteration in different ways. A change of molecular constitution without essential change of composition, i.e., by *paramorphism* (using the word rather broadly), may result in the formation of some variety of amphibole. Thus, the white pyroxene crystals of Canaan, Conn., are often changed on the exterior to tremolite; similarly with other varieties at many localities. See *uralite*, p. 401. Also changed to steatite, serpentine, etc.

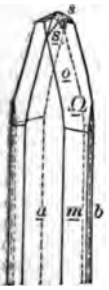
ACMITE. ÆGIRITE.

Monoclinic. Axes: $\grave{a} : \bar{b} : \acute{c} = 1{\cdot}0996 : 1 : 0{\cdot}6012$; $\beta = 73° 11'$.

Twins: tw. pl. *a*, very common; crystals often polysynthetic, with enclosed twinning lamellæ. Crystals long prismatic, vertically striated or channeled; acute terminations very characteristic.

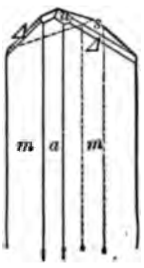
The above applies to ordinary *acmite*. For *ægirite*, crystals prismatic, bluntly terminated: twins not common; also in groups or tufts of slender acicular to capillary crystals, and in fibrous forms.

775.



Acmite.

775*a*.



Ægirite.

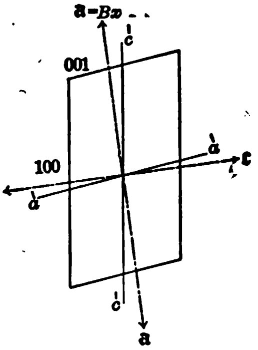
Cleavage: *m* distinct; *b* less so. Fracture uneven. Brittle. H. = 6–6·5. G. = 3·50–3·55 Bgr. Luster vitreous, inclining to resinous. Streak pale yellowish gray. Color brownish or reddish brown, green; in the fracture blackish green. Subtransparent to opaque. Optically –. Ax. pl. ‖ *b*. $Bx_a \wedge \dot{c} = \mathfrak{a} \wedge \dot{c} = +2\frac{1}{2}°$ acmite, to 6° ægirite. $\beta_y = 1·808$; $\gamma - \alpha = 0·052$.

Var.—Includes *acmite* in sharp-pointed crystals (Fig. 775) often twins. $Bx_a \wedge \dot{c} = 5\frac{1}{2}°–6°$. Also *ægirite* (Fig. 775*a*) in crystals bluntly terminated, twins rare, $Bx_a \wedge \dot{c} = 2\frac{1}{2}°–3\frac{1}{2}°$.

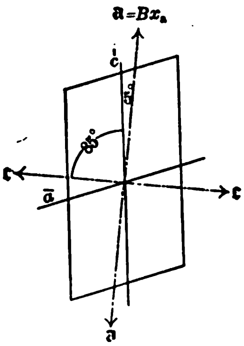
Crystals of acmite often show a marked zonal structure, green within and brown on the exterior, particularly ‖ *a*, *b*, *p* ($\bar{1}01$), *s* ($\bar{1}11$). The brown portion (acmite) is feebly pleochroic, the green (ægirite) strongly pleochroic. Both have absorption $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$, but the former has $\mathfrak{a}$ light brown with tinge of green, $\mathfrak{b}$ greenish yellow with tinge of brown, $\mathfrak{c}$ brownish yellow; the latter has $\mathfrak{a}$ deep grass-green, $\mathfrak{b}$ lighter grass-green, $\mathfrak{c}$ yellowish brown to yellowish.

With some authors (vom Rath, etc.) *s* = (011) and $\mathfrak{a} \wedge \dot{c} = -2°$ to $-6°$, as in Fig. 776*a*. Fig. 776 shows the optical orientation according to Brögger.

776.



776*a*.



Comp.—Essentially $\mathrm{Na\overset{III}{Fe}(SiO_3)_2}$, or $\mathrm{Na_2O.Fe_2O_3.4SiO_2}$ = Silica 52·0, iron sesquioxide 34·6, soda 13·4 = 100. Ferrous iron is also present.

Pyr., etc.—B.B. fuses at 2 to a lustrous black magnetic globule, coloring the flame deep yellow; with the fluxes reacts for iron and sometimes manganese. Slightly acted upon by acids.

Diff.—Ægirite is characterized in thin sections by its grass-green color; strong pleochroism in tones of green and yellow; the small extinction-angle in sections ‖ *b* (010). Distinguished from common green hornblende, with which it might be confounded, by the fact that in such sections the direction of extinction lying near the cleavage is negative ($\mathfrak{a}$), while the same direction in hornblende is positive ($\mathfrak{c}$).

Obs.—The original *acmite* occurs at Rundemyr, east of the little lake called Rokebergskjern, in the parish of Eker, near Kongsberg, Norway, in a pegmatite vein; it is in slender crystals, sometimes a foot long, embedded in feldspar and quartz.

Ægirite occurs especially in igneous rocks rich in soda and containing iron; thus in ægirite-granite, nephelite-syenite, and some varieties of phonolite; often in such cases iron-ore grains are wanting in the rock, their place being taken by ægirite crystals. In the sub-variety of phonolite called tinguaite, the rock has often a deep greenish color due to the abundance of minute crystals of ægirite. Large crystals are found in the pegmatite facies of nephelite-syenites as in West Greenland, Southern Norway, the peninsula Kola in Russian Lapland, Ditro in Transylvania.

Prominent American occurrences are the following: Magnet Cove, Arkansas (large crystals); Montreal; Salem, Mass.; Libertyville, N. J. (dike); Trans Pecos district in Texas (Osann); Black Hills; Cripple Creek, Colorado; Bearpaw Mts. and Judith Mts. (Pirsson), and the Crazy Mts. (Wolff) in Montana.

Acmite is named from *ἀκμή*, *point*, in allusion to the pointed extremities of the crystals; *Ægirite* is from Ægir, the Icelandic god of the sea.

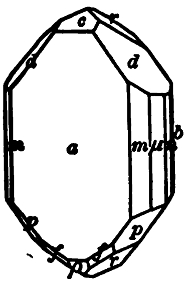
SPODUMENE. Triphane.

Monoclinic. Axes: $\grave{a} : \bar{b} : \grave{c}$ = 1·1238 : 1 : 0·6355; β = 69° 40′.

Twins: tw. pl. *a*. Crystals prismatic (mm''' = 93° 0′), often flattened ‖ *a*; the vertical planes striated and furrowed; crystals sometimes very large. Also massive, cleavable.

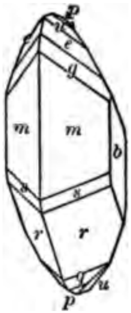
Cleavage: *m* perfect. A lamellar structure ‖ *a* sometimes very prominent, a crystal then separating into thin plates. Fracture uneven to subconchoidal. Brittle. H. = 6·5–7. G. = 3·13–3·20. Luster vitreous, on cleavage surfaces somewhat pearly. Color greenish white, grayish white, yellowish green, emerald-green, yellow, amethystine purple. Streak white. Transparent to translucent. Pleochroism strong in deep green varieties. Optically +. Ax. pl. ‖ $\bar{b}$. $Bx_a \wedge \grave{c}$ = + 26° Dx., = 24° to 25½° Greim. Dispersion $\rho > v$, horizontal. $2H_{a.y}$ = 64° 58½′; β_y = 1·669; $\gamma - \alpha$ = 0·016.

777.



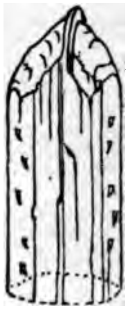
Norwich, Mass.

778.



Hiddenite.

779.



Hiddenite.

Hiddenite has a yellow-green to emerald-green color; the latter variety is used as a gem. In small (½ in. to 2 inches long) slender prismatic crystals, faces often etched.

Comp.—$LiAl(SiO_3)_2$ or $Li_2O.Al_2O_3.4SiO_2$ = Silica 64·5, alumina 27·4, lithia 8·4 = 100. Generally contains a little sodium; the variety hiddenite also chromium, to which the color may be due.

Pyr., etc.—B.B. becomes white and opaque, swells up, imparts a purple-red color (lithia) to the flame, and fuses at 3·5 to a clear or white glass. The powdered mineral, fused with a mixture of potassium bisulphate and fluorite on platinum wire, gives a more intense lithia reaction. Not acted upon by acids.

Diff.—Characterized by its perfect orthodiagonal parting (in some varieties) as well as by prismatic cleavage; has a higher specific gravity and more pearly luster than feldspar or scapolite. Gives a red flame B.B. Less fusible than amblygonite.

Obs.—Occurs on the island of Utö, Sweden; at Killiney Bay, Ireland; in small transparent crystals of a pale yellow in Brazil, province of Minas Geraës.

In the U. S., in granite at Goshen, Mass.; also at Chesterfield, Chester, Huntington (formerly Norwich), and Sterling, Mass.; at Windham, Maine, with garnet and staurolite; at Peru, with beryl, triphylite, petalite. In *Conn.*, at Branchville, the crystals often of immense size; near Stony Point, Alexander Co., N. C. (*hiddenite*); in South Dakota at the Etta tin mine in Pennington Co.

The name spodumene is from σποδιός, *ash-colored*. *Hiddenite* is named for W. E. Hidden of New York.

The spodumene at Goshen and Chesterfield is extensively altered; pseudomorphs occur of cymatolite (an intimate mixture of albite and muscovite with wavy fibrous structure and silky luster), killinite (pinite), muscovite, albite, quartz, and of "vein granite." Similar alteration-products occur at Branchville.

JADEITE.

Monoclinic. Axes, see p. 383. Cleavage and optical characters like pyroxene. Usually massive, with crystalline structure, sometimes granular, also obscurely columnar, fibrous foliated to closely compact.

Cleavage: prismatic, at angles of about 93° and 87°; also orthodiagonal, difficult. Fracture splintery. Extremely tough. H. = 6·5–7. G. = 3·33–3·35. Luster subvitreous, pearly on surfaces of cleavage. Color apple-green to nearly emerald-green, bluish green, leek-green, greenish white, and nearly white; sometimes white with spots of bright green. Optically biaxial, negative. $Bx_a \wedge \dot{c} = 30°$ to $40°$, $2H_{a.y} = 82° 48'$. Streak uncolored. Translucent to subtranslucent.

Comp.—Essentially a metasilicate of sodium and aluminium corresponding to spodumene, $NaAl(SiO_3)_2$ or $Na_2O.Al_2O_3.4SiO_2$ = Silica 59·4, alumina 25·2, soda 15·4 = 100.

Chloromelanite is a dark green to nearly black kind of jadeite (hence the name), containing iron sesquioxide and not conforming exactly to the above formula.

Pyr., etc.—B.B. fuses readily to a transparent blebby glass. Not attacked by acids after fusion, and thus differing from saussurite.

Obs.—Occurs chiefly in eastern Asia, thus in the Mogoung distr. in Upper Burma, in a valley 25 miles southwest of Meinkhoom, in rolled masses in a reddish clay; in Yungchang, province of Yunnan, southern China; in Thibet. Much uncertainty prevails, however, as to the exact localities, since jadeite and nephrite have usually been confounded together. May occur also on the American continent, in Mexico and South America; perhaps also in Europe.

Jadeite has long been highly prized in the East, especially in China, where it is worked into ornaments and utensils of great variety and beauty. It is also found with the relics of early man, thus in the remains of the lake-dwellers of Switzerland, at various points in France, in Mexico, Greece, Egypt, and Asia Minor.

A pyroxene, resembling jadeite in structure and consisting of the molecules of jadeite, diopside, and acmite in nearly equal proportions, occurs at the manganese mines of St. Marcel, Italy (Penfield).

Jade is a general term used to include various mineral substances of tough compact texture and nearly white to dark green color used by early man for utensils and ornaments, and still highly valued in the East, especially in China. It includes properly two species only; *nephrite*, a variety of amphibole (p. 401), either tremolite or actinolite, with G. = 2·95–3·0, and *jadeite*, of the pyroxene group and in composition a soda-spodumene, with G. = 3·3–3·35; easily fusible.

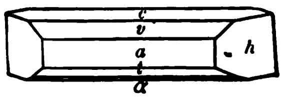
The jade of China belongs to both species, so also that of the Swiss lake-habitations and of Mexico. Of the two, however, the former, nephrite, is the more common and makes the jade (ax stone or Punamu stone) of the Maoris of New Zealand; also found in Alaska.

The name jade is also sometimes loosely used to embrace other minerals of more or less similar characters, and which have been or might be similarly used—thus sillimanite, pectolite, serpentine; also vesuvianite, garnet. Bowenite is a jade-like variety of serpentine. The "jade tenace" of de Saussure is now called saussurite.

WOLLASTONITE. Tabular Spar. Tafelspath *Germ.*

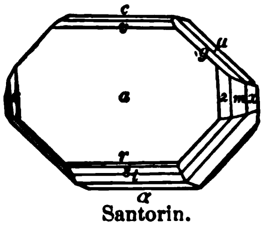
Monoclinic. Axes $\grave{a} : \bar{b} : \dot{c} = 1{\cdot}0531 : 1 : 0{\cdot}9676$; $\beta = 84° 30'$.

780.



Diana, N. Y.

781.



Santorin.

mm''', $110 \wedge 1\bar{1}0 = 92° 42'$.
hh''', $540 \wedge 5\bar{4}0 = 79° 58'$.
gg', $011 \wedge 0\bar{1}1 = 87° 51'$.
cv, $001 \wedge 101 = 40° 3'$.
cr, $001 \wedge \bar{3}01 = 74° 59'$.
ct, $001 \wedge \bar{1}01 = 45° 5'$.

Twins: tw. pl. *a*. Crystals commonly tabular ∥ *a* or *c*; also short prismatic. Usually cleavable massive to fibrous, fibers parallel or reticulated; also compact.

Cleavage: *a* perfect; also *c*; *t* ($\bar{1}01$) less so. Fracture uneven. Brittle. H. = 4·5–5. G. = 2·8–2·9. Luster vitreous, on cleavage surfaces pearly. Color white, inclining to gray, yellow, red, or brown. Streak white. Subtransparent to translucent. Optically –. $Bx_a \wedge \dot{c} = +37° 40'$. Dispersion

$\rho > v$ weak; inclined strong. Ax. pl. ‖ *b*. $2E_r = 70° 40'$; $\beta = 1{\cdot}633$; $\gamma - \alpha = 0{\cdot}014$.

Comp.—Calcium metasilicate, $CaSiO_3$ or $CaO.SiO_2$ = Silica 51·7, lime 48·3, = 100.

Pyr., etc.—In the matrass no change. B.B. fuses easily on the edges; with some soda, a blebby glass; with more, swells up and is infusible. With hydrochloric acid decomposed with separation of silica; most varieties effervesce slightly from the presence of calcite. Often phosphoresces.

Obs.—Wollastonite is found especially in granular limestone, and in regions of granite, as a contact formation; also in ejected masses in connection with basalt and lavas. It is often associated with a lime garnet, diopside, etc.

Occurs in the copper mines of Cziklowa in the Banat; at Orawitza; at Dognaczka and Nagyág; at Pargas in Finland; at Harzburg in the Harz; at Auerbach, in granular limestone; at Vesuvius, rarely in fine crystals; on Elba; on Santorin.

In the U. S., in *N. York*, at Willsborough; Diana, Lewis Co.; Bonaparte Lake, Lewis Co. In *Penn.*, Bucks Co., 3 m. w. of Attleboro'. In *Canada*, at Grenville; at St. Jérôme and Morin, Quebec, with apatite.

Named after the English chemist, W. H. Wollaston (1766–1828).

PECTOLITE.

Monoclinic. Axes: $\grave{a} : \bar{b} : \acute{c} = 1{\cdot}1140 : 1 : 0{\cdot}9864$; $\beta = 84° 40'$.

Commonly in close aggregations of acicular crystals; elongated ‖ $\bar{b}$, but rarely terminated. Fibrous massive, radiated to stellate.

Cleavage: *a* perfect; *c* also perfect. Fracture uneven. Brittle. H. = 5. G. = 2·68–2·78. Luster of the surface of fracture silky or subvitreous. Color whitish or grayish. Subtranslucent to opaque. Optically +. Ax. pl. and $Bx_a \perp b$; Bx_o nearly $\perp a$; $2H_o = 143°–145°$.

Comp., Var.—$HNaCa_2(SiO_3)_3$ or $H_2O.Na_2O.4CaO.6SiO_2$ = Silica 54·2, lime 33·8, soda 9·3, water 2·7 = 100.

Pectolite is sometimes classed with the hydrous species allied to the zeolites.

Pyr., etc.—In the closed tube yields water. B.B. fuses at 2 to a white enamel. Decomposed in part by hydrochloric acid with separation of silica as a jelly. Often gives out light when broken in the dark.

Obs.—Occurs mostly in basic eruptive rocks, in cavities or seams; occasionally in metamorphic rocks. Found in Scotland near Edinburgh; at Kilsyth, Costorphine Hill (*walkerite*); I. Skye. Also at Mt. Baldo and Mt. Monzoni in the Tyrol; at Niederkirchen, Bavaria (*osmelite*).

Occurs also at Bergen Hill and Paterson, N. J.; Lehigh Co., Penn.; compact at Isle Royale, L. Superior; at Magnet Cove, Ark., in elæolite-syenite (*manganpectolite* with 4 p. c. MnO); compact, massive in Alaska, where used, like jade, for implements.

Rosenbuschite. Near pectolite, but contains zirconium. From Norway.

Wöhlerite. A zirconium-silicate and niobate of Ca, Na, etc. In prismatic, tabular crystals, yellow to brown. Occurs in elæolite-syenite, on several islands of the Langesund fiord, near Brevik, in Norway.

Låvenite. A complex zirconium-silicate of Mn, Ca, etc., containing also F, Ti, Ta, etc. In yellow to brown prismatic crystals. Found on the island Låven in the Langesund fiord, southern Norway; also elsewhere in elæolite-syenite.

γ. Triclinic Section.

RHODONITE.

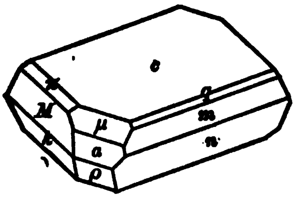
Triclinic. Axes $\breve{a} : \bar{b} : \acute{c} = 1{\cdot}07285 : 1 : 0{\cdot}6213$; $\alpha = 103° 18'$; $\beta = 108° 44'$; $\gamma = 81° 39'$.

Crystals usually large and rough with rounded edges. Commonly tabular ‖ *c*; sometimes resembling pyroxene in habit. Commonly massive, cleavable to compact; also in embedded grains.

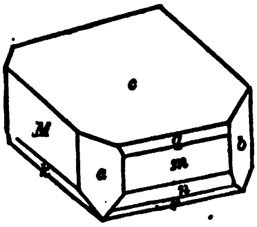
Cleavage: *m*, *M* perfect; *c* less perfect. Fracture conchoidal to uneven; very tough when compact. H. = 5·5–6·5. G. = 3·4–3·68. Luster vitreous; on cleavage-surfaces somewhat pearly. Color light brownish red, flesh-red, rose-pink; sometimes greenish or yellowish, when impure; often black outside from exposure. Streak white. Transparent to translucent.

Comp., Var.—Manganese metasilicate, $MnSiO_3$ or $MnO.SiO_2$ = Silica 45·9, manganese protoxide 54·1 = 100. Iron, calcium (in *bustamite*), and occasionally zinc (in *fowlerite*) replace part of the manganese.

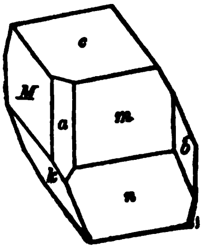
782.



783.



784.



Franklin Furnace, N. J.

ab, 100 $\wedge$ 010 = 94° 26′.
ac, 100 $\wedge$ 001 = 72° 36½′.
bc, 010 $\wedge$ 001 = 78° 42½′.
am, 100 $\wedge$ 110 = 48° 33′.
mM, 110 $\wedge$ $1\bar{1}0$ = 92° 28½′.
cn, 001 $\wedge$ $\bar{2}\bar{2}1$ = 73° 52′.
ck, 001 $\wedge$ $\bar{2}21$ = 62° 28′.
kn, $\bar{2}21$ $\wedge$ $\bar{2}\bar{2}1$ = 86° 5′.

Pyr., etc.—B.B. blackens and fuses with slight intumescence at 2·5; with the fluxes gives reactions for manganese; fowlerite gives with soda on charcoal a reaction for zinc. Slightly acted upon by acids. The calciferous varieties often effervesce from mechanical admixture of calcium carbonate. In powder, partly dissolves in hydrochloric acid, and the insoluble part becomes of a white color. Darkens on exposure to the air, and sometimes becomes nearly black.

Diff.—Characterized by its pink color; distinct cleavages; fusibility and manganese reactions B.B.

Obs.—Occurs at Långban, Wermland, Sweden, in iron-ore beds, in broad cleavage-plates, and also granular massive; at the Pajsberg iron mines near Filipstad (*paisbergite*) sometimes in small brilliant crystals; in the district of Ekaterinburg in the Ural massive like marble, whence it is obtained for ornamental purposes; with tetrahedrite at Kapnik and Rezbánya, Hungary; St. Marcel, Piedmont; Mexico (*bustamite*, containing CaO).

Occurs in Cummington, Mass.; on Osgood's farm, Blue Hill Bay, Maine; *fowlerite* (containing ZnO) at Mine Hill, Franklin Furnace, and Sterling Hill, near Ogdensburgh, N. J., usually embedded in calcite and sometimes in fine crystals.

Named from *ρoδov*, *a rose*, in allusion to the color.

Rhodonite is often altered chiefly by oxidation of the MnO (as in *marceline*, *dyssnite*); also by hydration (*stratopeite*, *neotocite*, etc.); further by introduction of CO_2 (*allagite*, *photicite*, etc.).

Babingtonite. $(Ca,Fe,Mn)SiO_3$ with $Fe_2(SiO_3)_3$. In small black triclinic crystals, near rhodonite in angle (axes on p. 383). H. = 5·5–6. G. = 3·35–3·37. From Arendal, Norway; at Herbornseelbach, Nassau; at Baveno, Italy.

Hiortdahlite. Essentially $(Na_2,Ca)(Si,Zr)O_3$, with also fluorine. In pale yellow tabular crystals (triclinic). Occurs sparingly on an island in the Langesund fiord, southern Norway.

3. Amphibole Group.

Orthorhombic, Monoclinic, Triclinic.

Composition for the most part that of a metasilicate, $RSiO_3$, with R = Ca,Mg,Fe chiefly, also $Mn,Na_2,(K_2),H_2$. Further often containing aluminium and ferric iron, in part with alkalies as $NaAl(SiO_3)_2$ or $NaFe(SiO_3)_2$; perhaps also containing $\overset{II}{R}\overset{III}{R}_2SiO_6$.

α. *Orthorhombic Section.*

		$\breve{a} : \bar{b}$
Anthophyllite	$(Mg,Fe)SiO_3$	0·5138 : 1
GEDRITE	$(Mg,Fe)SiO_3$ with $(Mg,Fe)Al_2SiO_6$	

β. *Monoclinic Section.*

		$\grave{a} : \bar{b} : \acute{c}$	β
Amphibole		0·5511 : 1 : 0·2938	73° 58′
I. *NONALUMINOUS VARIETIES.*			
1. TREMOLITE	$CaMg_3(SiO_3)_4$		
2. ACTINOLITE	$Ca(Mg,Fe)_3(SiO_3)_4$		
Nephrite, Asbestus,	Smaragdite, etc.		
Cummingtonite	$(Fe,Mg)SiO_3$		
Dannemorite	$(Fe,Mn,Mg)SiO_3$		
Grünerite	$FeSiO_3$		
3. RICHTERITE	$(K_2,Na_2,Mg,Ca,Mn)_4(SiO_3)_4$		
II. *ALUMINOUS VARIETIES.*			
4. HORNBLENDE			
Edenite Pargasite and Common Hornblende	Chiefly $Ca(Mg,Fe)_3(SiO_3)_4$ with $Na_2Al_2(SiO_3)_4$ and $(Mg,Fe)_2(Al,Fe)_4Si_2O_{12}$		
Glaucophane	$NaAl(SiO_3)_2.(Fe,Mg)SiO_3$		
		$\grave{a} : \bar{b} : \acute{c}$	β
Riebeckite	$2NaFe(SiO_3)_2.FeSiO_3$	0·5475 : 1 : 0·2925 =	76° 10′
Crocidolite	$NaFe(SiO_3)_2.FeSiO_3$		
Arfvedsonite	$Na_8(Ca,Mg)_3(Fe,Mn)_{14}(Al,Fe)_2Si_{21}O_{45}$	0·5509 : 1 : 0·2378 =	73° 2′

γ. *Triclinic Section.*

Ænigmatite.

The only species included under the triclinic section is the rare and imperfectly known ænigmatite (cossyrite).

The AMPHIBOLE GROUP embraces a number of species which, while falling in different systems, are yet closely related in form—as shown in the common prismatic cleavage of 54° to 56°—also in optical characters and chemical composition. As already noted (see p. 383), the species of this group form chemically a series parallel to that of the closely allied Pyroxene Group, and between them there is a close relationship in crystalline form and other characters. The Amphibole Group, however, is less fully developed, including fewer species, and those known show less variety in form.

The chief *distinctions* between pyroxene and amphibole proper are the following:

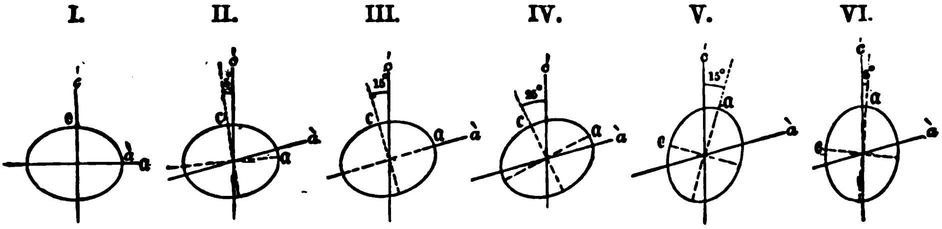
Prismatic angle with pyroxene 87° and 93°; with amphibole 56° and 124°; the prismatic cleavage being much more distinct in the latter.

With pyroxene, crystals usually short prismatic and often complex, structure of massive kinds mostly lamellar or granular; with amphibole, crystals chiefly long prismatic and simple, columnar and fibrous massive kinds the rule.

The specific gravity of most of the pyroxene varieties is higher than of the like varieties of amphibole. In composition of corresponding kinds, magnesium is present in larger amount in amphibole (Ca : Mg = 1 : 1 in diopside, = 1 : 3 in tremolite); alkalies more frequently play a prominent part in amphibole.

The optical relations of the prominent members of the group, as regards the position of the ether-axes, is exhibited by the following figures (Cross); compare Fig. 751, p. 384, for a similar representation for the corresponding members of the pyroxene group.

785.



I. Anthophyllite. II. Glaucophane. III. Tremolite, etc. IV. Hornblende. V. Arfvedsonite. VI. Riebeckite.

---

a. Orthorhombic Section.

ANTHOPHYLLITE.

Orthorhombic. Axial ratio $\breve{a} : \bar{b} = 0{\cdot}5137 : 1$. Crystals rare, habit prismatic ($mm''' = 54° 23$). Commonly lamellar, or fibrous massive; fibers often very slender; in aggregations of prisms.

Cleavage: prismatic, perfect; *b* less so; *a* sometimes distinct. H. = 5·5–6. G. = 3·1–3·2. Luster vitreous, somewhat pearly on the cleavage-face. Color brownish gray, yellowish brown, clove-brown, brownish green, emerald-green, sometimes metalloidal. Streak uncolored or grayish. Transparent to subtranslucent. Sometimes pleochroic. Usually optically +; also + for red, − for yellow, green. Ax. pl. always ∥ *b*. Bx_a usually ⊥ *c*; also ⊥ *c* for red, ⊥ *a* for yellow, green. Axial angle large. $\beta = 1{\cdot}642$; $\gamma - \alpha = 0{\cdot}024$.

Comp., Var.—$(Mg,Fe)SiO_3$, corresponding to enstatite-bronzite-hypersthene in the pyroxene group. Aluminium is sometimes present in considerable amount. There is the same relation in optical character between anthophyllite (+) and gedrite (−) as between enstatite and hypersthene (cf. Figs. 753, 754, p. 385).

Var.—ANTHOPHYLLITE, Mg : Fe = 4 : 1, 3 : 1, etc. For 8 : 1, the percentage composition is: Silica 55·6, iron protoxide 16·6, magnesia 27·8 = 100. Anthophyllite sometimes occurs in forms resembling asbestus.

Aluminous, GEDRITE. Iron is present in larger amount, and also aluminium; it hence corresponds nearly to a hypersthene, some varieties of which are highly aluminous.

Hydrous anthophyllites have been repeatedly described, but in most cases they have been shown to be hydrated monoclinic amphiboles.

Pyr, etc.—B.B. fuses with difficulty to a black magnetic enamel; with the fluxes gives reactions for iron; unacted upon by acids.

Obs.—Anthophyllite occurs in mica schist near Kongsberg in Norway; at Hermannschlag, Moravia. In the U. S., at the Jenks corundum mine, Franklin, Macon Co., N. C.

The original *gedrite* is from the valley of Héas, near Gèdres, France. Named from *anthophyllum*, *clove*, in allusion to the clove-brown color.

β. *Monoclinic Section.*

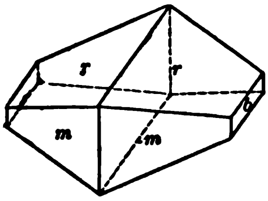
AMPHIBOLE. Hornblende.

Monoclinic. Axes $\grave{a} : \grave{b} : \acute{c} = 0{\cdot}5511 : 1 : 0{\cdot}2938$; $\beta = 73° 58'$.

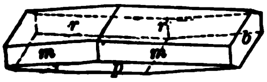
mm''',	$110 \wedge 1\bar{1}0 = 55° 49'$.	*rr'*,	$011 \wedge 0\bar{1}1 = 31° 32'$.
ca,	$001 \wedge 100 = 73° 58'$.	*ii*,	$031 \wedge 0\bar{3}1 = 80° 32'$.
cp,	$001 \wedge \bar{1}01 = 31° 0'$.	*pr*,	$\bar{1}01 \wedge 011 = 34° 25'$.

Twins: (1) tw. pl. *a*, common as contact-twins; rarely polysynthetic. (2) *c*, as tw. lamellæ, occasionally producing a parting analogous to that more common with pyroxene (Fig. 430, p. 131). Crystals commonly prismatic; usually terminated by the low clinodome, *r* (011), sometimes by *r* and *p* ($\bar{1}01$) equally developed and then suggesting rhombohedral forms (as of tourmaline).

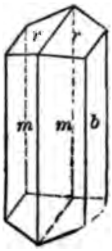
786.



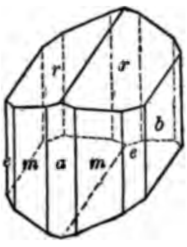
787.



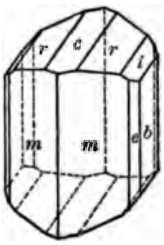
788.



789.



790.



Also columnar or fibrous, coarse or fine, fibers often like flax; rarely lamellar; also granular massive, coarse or fine, and usually strongly coherent, but sometimes friable.

Cleavage: *m* highly perfect; *a*, *b* sometimes distinct. Fracture subconchoidal, uneven. Brittle. H. = 5–6. G. = 2·9–3·4, varying with the composition. Luster vitreous to pearly on cleavage-faces; fibrous varieties often silky. Color between black and white, through various shades of green, inclining to blackish green; also dark brown; rarely yellow, pink, rose-red. Streak uncolored, or paler than color. Sometimes nearly transparent; usually subtranslucent to opaque.

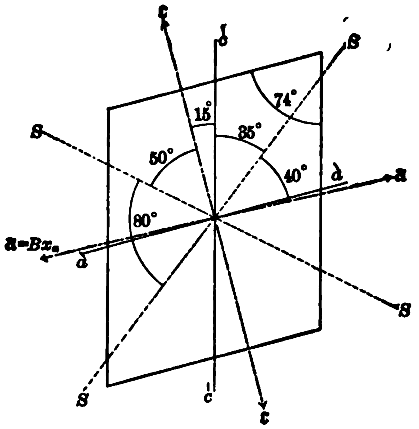
Pleochroism strongly marked in all the deeply colored varieties, as described beyond. Absorption usually $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Optically −, rarely +. Ax. pl. ∥ *b*. Extinction-angle on *b*, or $\mathfrak{c} \wedge \acute{c} = +15°$ to 18° in most cases, but varying from about 1° up to 37°; hence also $Bx_a \wedge \acute{c} = -75°$ to $-72°$, etc. See Fig. 791. Dispersion $\rho < v$. Axial angles variable; see beyond.

Comp., Var.—In part a normal metasilicate of calcium and magnesium, $RSiO_3$, usually with iron, also manganese, and thus in general analogous to the pyroxenes. The alkali metals, sodium and potassium, also present, and more commonly so than with pyroxene. In part also aluminous, corresponding to the aluminous pyroxenes. Titanium sometimes is present and also rarely fluorine in small amount.

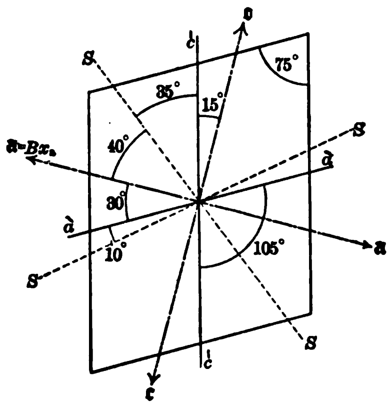
The aluminium is in part present as $NaAl(SiO_3)_2$, but many amphiboles containing aluminium or ferric iron are more basic than a normal metasilicate; they may sometimes be explained as containing $\overset{\text{II}}{R}(Al,\overset{\text{III}}{Fe})_2SiO_6$, but the exact nature of the compound is often doubtful. The amphibole formulas are in many cases double the corresponding ones for pyroxene. Thus, for most tremolite and actinolite, Ca : Mg(Fe) = 1 : 3, and hence tremolite is $CaMg_3Si_4O_{12}$, while diopside is $CaMgSi_2O_6$, etc.

Rammelsberg has shown that the composition of most aluminous amphiboles may be expressed in the general form $m\mathrm{RSiO_3}.n\mathrm{Al_2O_3}$; while Scharizer, modifying this view, proposes to regard the amphiboles as molecular compounds of $Ca(Mg,Fe)_3Si_4O_{12}$ (actinolite), and the orthosilicate $(\overset{\mathrm{I}}{R}_2,\overset{\mathrm{II}}{R})_3\overset{\mathrm{III}}{R}_2Si_3O_{12}$, for which he uses Breithaupt's name ***syntagmatite***, originally given to the Vesuvian hornblende.

791.



791*a*.



The crystallographic position here adopted is that suggested by Tschermak, which best exhibits the relation between amphibole and pyroxene. Some authors retain the former position, according to which $p = (001)$, $r = (\bar{1}11)$, etc. Fig. 791*a* shows the corresponding optical orientation.

I. *Containing little or no Aluminium.*

1. TREMOLITE. Grammatite, nephrite pt. *Calcium-magnesium amphibole.* Formula $CaMg_3(SiO_3)_4$ = Silica 57·7, magnesia 28·9, lime 13·4 = 100. Ferrous iron, replacing the magnesium, present only sparingly, up to 3 p. c. Colors white to dark gray. In distinct crystals, either long-bladed or short and stout. In aggregates long and thin columnar, or fibrous; also compact granular massive (nephrite, p. 401). G. = 2·9–3·1. Sometimes transparent and colorless. Optically −. Extinction-angle on *b*, or $\mathfrak{c} \wedge \dot{c} = +16°$ to 18°, hence $Bx_a \wedge \dot{c} = -74°$ to $-72°$. $2V_y = 80°$ to 88°. $\beta_y = 1{\cdot}621$; $\gamma - \alpha = 0{\cdot}027$.

Tremolite was named by Pini from the Tremola valley on the south side of the St. Gothard.

2. ACTINOLITE. Strahlstein *Germ.* *Calcium-magnesium-iron amphibole.* Formula $Ca(Mg,Fe)_3(SiO_3)_4$. Color bright green and grayish green. In crystals, either short- or long-bladed, as in tremolite; columnar or fibrous; granular massive. G. = 3–3·2. Sometimes transparent. The variety in long bright-green crystals is called *glassy actinolite;* the crystals break easily across the prism. The fibrous and radiated kinds are often called *asbestiform actinolite and radiated actinolite.* Actinolite owes its green color to the ferrous iron present.

Pleochroism distinct, increasing as the amount of iron increases, and hence the color becomes darker: $\mathfrak{c}$ emerald-green, $\mathfrak{b}$ yellow-green, $\mathfrak{a}$ greenish yellow.

Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ Zillerthal, Tschermak. Optically −. Extinction-angle on b, $\mathfrak{c} \wedge \dot{c} = +15^\circ$ and $Bx_a \wedge \dot{c} = -75^\circ$. $2V_y = 80^\circ$; $\rho < v$; $\beta_y = 1{\cdot}627$; $\gamma - \alpha = 0{\cdot}025$.

Named actinolite from *ἀκτίν*, *a ray*, and *λίθος*, *stone*, a translation of the German *Strahlstein* or *radiated stone*. Name changed to *actinote* by Haüy, without reason.

Nephrite. Jade pt. A tough, compact, fine-grained tremolite (or actinolite), breaking with a splintery fracture and glistening luster. H. = 6–6·5. G. = 2·96–3·1. Named from a supposed efficacy in diseases of the kidney, from *νεφρός*, *kidney*. It varies in color from white (tremolite) to dark green (actinolite), in the latter iron protoxide being present up to 6 or 7 p. c. The latter kind sometimes encloses distinct prismatic crystals of actinolite. A derivation from an original pyroxenic mineral has been suggested in some cases. Nephrite or jade was brought in the form of carved ornaments from Mexico or Peru soon after the discovery of America. A similar stone comes from Eastern Asia, New Zealand and Alaska See jadeite, p. 393; jade, p. 394.

Asbestus. Asbestos. Asbest *Germ.* Tremolite, actinolite, and other varieties of amphibole, excepting those containing much alumina, pass into fibrous varieties, the fibers of which are sometimes very long, fine, flexible, and easily separable by the fingers, and look like flax. These kinds are called *asbestus* (fr. the Greek for *incombustible*). The colors vary from white to green and wood-brown. The name *amianthus* is applied usually to the finer and more silky kinds. Much that is popularly called asbestus is *chrysotile*, or fibrous serpentine, containing 12 to 14 p. c. of water. *Byssolite* is a stiff fibrous variety.

Mountain leather is in thin flexible sheets, made of interlaced fibers; and *mountain cork* the same in thicker pieces; both are so light as to float on water, and they are often hydrous, color white to gray or yellowish. *Mountain wood* is compact fibrous, and gray to brown in color, looking a little like dry wood.

Smaragdite. A thin-foliated variety of amphibole, near actinolite in composition but carrying some alumina. It has a light grass-green color, resembling much common green diallage. In many cases derived from pyroxene (diallage) by uralitization, see below. It retains much of the structure of the diallage and also often encloses remnants of the original mineral. It forms, along with whitish or greenish saussurite, a rock called saussurite-gabbro, the euphotide of the Alps. The original mineral is from Corsica, and the rock is the *verde di Corsica duro* of the arts.

Uralite. Pyroxene altered to amphibole. The crystals, when distinct, retain the form of the original mineral, but have the cleavage of amphibole. The change usually commences on the surface, transforming the outer layer into an aggregation of slender amphibole prisms, parallel in position to each other and to the parent pyroxene (cf. Fig. 760, p. 386). When the change is complete the entire crystal is made up of a bundle of amphibole needles or fibers. The color varies from white (tremolite) to pale or deep green, the latter the more common. In composition uralite appears to conform nearly to actinolite, as also in optical characters. The most prominent change in composition in passing from the original pyroxene is that corresponding to the difference existing between the two species in general, that is, an increase in the magnesium and decrease in calcium. The change, therefore, is not strictly a case of paramorphism, although usually so designated. Uralite was originally described by Rose in a rock from the Ural. It has since been observed from many localities. The microscopic study of rocks has shown the process of "uralitization" to be very common, and some authors regard many hornblendic rocks and schists to represent altered pyroxenic rocks on a large scale.

Cummingtonite. Amphibole-Anthophyllite. *Iron-Magnesium Amphibole.* Here belong certain varieties of amphibole resembling anthophyllite and essentially identical with it in composition, but optically monoclinic. From Kongsberg; Greenland. The original *cummingtonite* is gray to brown in color; usually fibrous or fibro-lamellar, often radiated. G. = 3·1–3·32; from Cummington, Mass.

Dannemorite. *Iron-Manganese Amphibole.* Color yellowish brown to greenish gray. Columnar or fibrous, like tremolite and asbestus. Contains iron and manganese. From Sweden.

Grünerite. *Iron-Amphibole.* Asbestiform or lamellar-fibrous. Luster silky; color brown; G. = 3·713. Formula $FeSiO_3$.

3. RICHTERITE. *Sodium-Magnesium-Manganese Amphibole.* $(K_2,Na_2,Mg,Ca,Mn)_4(SiO_3)_4$.

In elongated crystals, seldom terminated. G. = 3·09. Color brown, yellow, rose-red. Transparent to translucent. $\mathfrak{c} \wedge \dot{c} = +17^\circ–20^\circ$; $\beta_y = 1{\cdot}63$; $\gamma - \alpha = 0{\cdot}024$. From Pajsberg and Långban, Sweden. Characterized by the presence of manganese and alkalies in relatively large amount.

Breislakite occurs in wool-like forms at Vesuvius and Capo di Bove. Color dark brown to black, pleochroism strongly marked. Inferred to belong near richterite.

II. *Aluminous.*

4. ALUMINOUS AMPHIBOLE. Hornblende. Contains alumina or ferric iron, and usually both, with ferrous iron (sometimes manganese), magnesium, calcium, and alkalies. The kinds here included range from the light-colored *edenite*, containing but little iron, through the light to dark green *pargasite*, to the dark-colored or black *hornblende*, the color growing darker with increase in amount of iron. Extinction-angle variable, from 0° to 37°, see below. Pleochroism strong. Absorption usually $\mathfrak{c} < \mathfrak{b} < \mathfrak{a}$.

EDENITE. *Aluminous Magnesium-Calcium Amphibole.* Color white to gray and pale green, and also colorless; G. = 3·0–3·059. Resembles anthophyllite and tremolite. Named from the locality at Edenville, N. Y. To this variety belong various pale-colored amphiboles, having less than 5 p. c. of iron oxides.

Koksharovite is a variety from the neighborhood of L. Baikal named after the Russian mineralogist, N. von Koksharov.

COMMON HORNBLENDE, PARGASITE. Colors bright or dark green, and bluish green to grayish black and black. G. = 3·05–3·47. *Pargasite* is usually made to include green and bluish-green kinds, occurring in stout lustrous crystals, or granular; and *Common hornblende* the greenish black and black kinds, whether in stout crystals or long-bladed, columnar, fibrous, or massive granular. But no line can be drawn between them. The extinction-angle on *b*, or $\mathfrak{c} \wedge \dot{c} = +15°$ to 25° chiefly. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

Pargasite occurs at Pargas, Finland, in bluish-green and grayish-black crystals. $\mathfrak{c} \wedge \dot{c} = +18°$; $\beta = 1·64$; $\gamma - \alpha = 0·019$; $2V = 59°$. Pleochroism: $\mathfrak{c}$ greenish blue; $\mathfrak{b}$ emerald-green; $\mathfrak{a}$ grn. yellow.

The dark brown to black *hornblendes* from basaltic and other igneous rocks vary somewhat widely in optical characters. The angle $\mathfrak{c} \wedge \dot{c} = 0°$ to $+10°$ chiefly; $\beta = 1·725$; $\gamma - \alpha = 0·072$ (maximum). Pleochroism: $\mathfrak{c}$ brown, $\mathfrak{b}$ yellow, $\mathfrak{a}$ yw. green, but variable.

The *Kataforite* of Norway (Brögger) has $\mathfrak{c} \wedge \dot{c} = 30°$ to 60°; absorption $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$; pleochroism: $\mathfrak{c}$ yellow, $\mathfrak{b}$ violet, $\mathfrak{a}$ yw. brown; it approximates toward arfvedsonite (p. 405).

Kupfferite, from a graphite mine in the Tunkinsk Mts., near L. Baikal, is a deep green amphibole (aluminous) formerly referred to anthophyllite.

Syntagmatite is the black hornblende of Vesuvius.

Bergamaskite is an iron-amphibole containing almost no magnesia. From Monte Altino, Province of Bergamo, Italy.

Kaersutite is a titaniferous amphibole from Kaersut, Umanaks fiord, North Greenland.

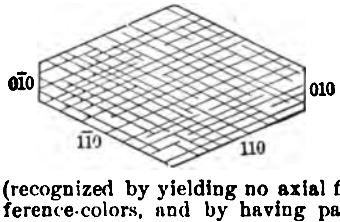
Hastingsite is an amphibole low in silica and high in iron and soda, from the nephelite-syenite of Dungannon, Hastings Co., Ontario.

Pyr.—Essentially the same as for the corresponding varieties of pyroxene, see p. 390.

Diff.—Distinguished from pyroxene (and tourmaline) by its distinct prismatic cleavage, yielding angles of 56° and 124°. Fibrous and columnar forms are much more common than with pyroxene, lamellar and foliated forms rare (see also pp. 390, 398). Crystals often long, slender, or bladed. Differs from the fibrous zeolites in not gelatinizing with acids. Epidote has a peculiar green color, is more fusible, and shows a different cleavage.

In rock sections amphibole generally shows distinct colors, green, sometimes olive or brown, and is strongly pleochroic. Also recognized by its high relief; generally rather high interference-colors; by the very perfect system of cleavage-cracks crossing at angles of 56° and 124° in sections ⊥ $\dot{c}$ (Fig. 792). In sections ‖ *b* (010) (recognized by yielding no axial figure in convergent light, by showing the highest interference-colors, and by having parallel cleavage-cracks, ‖ $\dot{c}$), the extinction-direction for common hornblendes makes a small angle (12°–15°) with the cleavage-cracks (*i.e.*, with $\dot{c}$); further, this direction is positive $\mathfrak{c}$ (different from common pyroxene and ægirite, cf. Figs. 772 and 776).

792.



Obs.—Amphibole occurs in many crystalline limestones, and granitic and schistose rocks, and sparingly in volcanic rocks. *Tremolite*, the magnesia-lime variety, is especially common in limestones, particularly magnesian or dolomitic; *actinolite* (also nephrite), the magnesia-lime-iron variety, in steatitic rocks and with serpentine; and dark green and black *hornblende*, in chlorite schist, mica schist, gneiss, and in various other rocks of which it forms a constituent part; brown to black hornblende occurs in trachyte and other eruptive rocks. Asbestus is often found in connection with serpentine.

Hornblende-rock, or *amphibolite*, consists of massive hornblende of a dark greenish black or black color, and has a granular texture. Occasionally the *green* hornblende, or actinolite, occurs in rock-masses, as at St. Francis, in Canada. *Hornblende-schist* has the same composition as amphibolite, but is schistose or slaty in structure. It often contains a little feldspar. In some varieties of it the hornblende is in part in minute needles. Granite and syenite often contain hornblende, and with diorite it is a common constituent. This is also true of the corresponding forms of gneiss. In these cases it is usually present in small, irregular masses, often fibrous in structure; also as rough bladed crystals.

Prominent foreign localities of amphibole are the following: *Tremolite* (grammatite) in dolomite at Campolongo, Switzerland; also at Orawitza, Rezbánya, Hungary; Gulsjö, Wermland, Sweden. *Actinolite* in the crystalline schists of the Central and Eastern Alps, especially at Greiner in the Zillerthal; at Zöblitz in Saxony; Arendal, Norway. *Asbestus* at Sterzing, Zillerthal, and elsewhere in Tyrol; in Savoy; also in the island of Corsica. *Pargasite* at Pargas, Finland; Saualpe in Carinthia. *Hornblende* at Arendal and Kongsberg, Norway; in Sweden and Finland; at Vesuvius; Aussig and Teplitz, Bohemia; etc. *Nephrite*, which in the form of "jade" ornaments and utensils is widely distributed among the relics of early man (see jade, p. 394), is obtained at various points in Central Asia. The most important source is that in the Karakash valley in the Kuen Lun Mts. on the southern borders of Turkestan; also other localities in Central Asia. In New Zealand. Nephrite has been found in Europe as a rolled mass at Schwemmsal near Leipzig; in Swiss Lake habitations and similarly elsewhere.

In the United States, in *Maine*, black crystals occur at Thomaston; pargasite at Phippsburg. In *Vermont*, actinolite in the steatite quarries of Windham and New Fane. In *Mass.*, tremolite at Lee; black crystals at Chester; asbestus at Pelham; *cummingtonite* at Cummington. In *Conn.*, in large flattened white crystals and in bladed and fibrous forms (tremolite) in dolomite, at Canaan. In *N. York*, Warwick, Orange Co.; near Edenville; near Amity; at the Stirling mines, Orange Co.; in short green crystals at Gouverneur, St. Lawrence Co.; with pyroxene at Russell; a black variety at Pierrepont; at Macomb; Pitcairn; tremolite at Fine; in Rossie, 2 m. N. of Oxbow; in large white crystals at Diana, Lewis Co.; asbestus near Greenwood Furnace. In *N. Jersey*, tremolite or gray amphibole in good crystals at Bryam, and other varieties of the species at Franklin and Newton, radiated actinolite. In *Penn.*, actinolite at Mineral Hill, in Delaware Co.; at Unionville; at Kennett, Chester Co. In *Maryland*, actinolite and asbestus at the Bare Hills in serpentine; asbestus is mined at Pylesville, Harford Co. In *Virginia*, actinolite at Willis's Mt., in Buckingham Co.; asbestus at Barnet's Mills, Fauquier Co. Nephrite occurs in Alaska.

In Canada, tremolite is abundant in the Laurentian limestones, at Calumet Falls, Litchfield, Pontiac Co., Quebec; also at Blythfield, Renfrew Co., and Dalhousie, Lanark Co. Black hornblende at various localities in Quebec and Ontario with pyroxene, apatite, titanite, etc., as in Renfrew Co. Asbestus and mountain cork at Buckingham, Ottawa Co., Quebec; a bed of actinolite at St. Francis, Beauce Co., Quebec; nephrite has been found in British Columbia and Northwest Territory.

GLAUCOPHANE.

Monoclinic; near amphibole in form. Crystals prismatic in habit, usually indistinct; commonly massive, fibrous, or columnar to granular.

Cleavage: *m* perfect. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 3·103–3·113. Luster vitreous to pearly. Color azure-blue, lavender-blue, bluish black, grayish. Streak grayish blue. Translucent. Pleochroism strongly marked: $\mathfrak{c}$ sky-blue to ultramarine-blue, $\mathfrak{b}$ reddish or bluish violet, $\mathfrak{a}$ yellowish green to colorless. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Optically +. Ax. pl. ∥ *b*. $\mathfrak{c} \wedge \dot{c} = 4°$ to 6°, rarely higher values. $2E_{a.r} = 84° 42'$. $\beta = 1·6442$ (gastaldite); $\gamma - \alpha = 0·022$.

Comp.—Essentially $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$. If Mg : Fe = 2 : 1, the formula requires: Silica 57·6, alumina 16·3, iron protoxide 7·7, magnesia 8·5, soda 9·9 = 100.

Obs.—Occurs as the hornblendic constituent of certain crystalline schists, called *glaucophane-schists*, or glaucophanite; also more or less prominent in mica schists, amphibolites, gneiss, eclogites, etc. It is often associated with mica, garnet, diallage and omphacite, epidote and zoisite, etc. First described from the island of Syra, one of the Cyclades; since shown to be rather widely distributed, as on the southern slope of the Alps (*gastaldite*), Corsica, Japan, etc. *Rhodusite* is a fibrous variety from the Is. Rhodus.

In the U. S., glaucophane schists have been described from the Coast Ranges of California, as at Sulphur Bank, Lake Co.

Glaucophane is named from γλαυκός, *bluish green*, and φαίνεσθαι, *to appear*.

RIEBECKITE.

Monoclinic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·5475 : 1 : 0·2925$; $\beta = 76° 10'$. In embedded prismatic crystals, longitudinally striated. Cleavage: prismatic (56°) perfect. Luster vitreous. Color black. Pleochroism very strongly marked: c green, b ($= \bar{b}$) deep blue, a (nearly ∥ c) dark blue. Optically —. Extinction-angle small, $a \wedge \dot{c} = 4°–5° (\pm?)$. Axial angle large.

Comp.—Essentially $2Na\overset{III}{Fe}(SiO_3)_2.FeSiO_3$ = Silica 50·5, iron sesquioxide 26·9, iron protoxide 12·1, soda 10·5 = 100. It corresponds closely to acmite (ægirite) among the pyroxenes.

Obs.—Originally described from the granite and syenite of the island of Socotra in the Indian Ocean, 120 m. N. E. of Cape Guardafui, the eastern extremity of Africa; occurs in groups of prismatic crystals, often radiating and closely resembling tourmaline; also in granophyre blocks found at Ailsa Crag and at other points in Scotland and Ireland. A similar amphibole occurs at Mynydd Mawr, Carnarvonshire, Wales. Also another in granulite in Corsica. A so-called arfvedsonite from St. Peter's Dome, Pike's Peak region, El Paso Co., Colorado, occurring with astrophyllite and zircon, is shown by Lacroix to be near riebeckite. Extinction-angle on b, $a \wedge \dot{c} = 3°$ to 4°.

CROCIDOLITE. Blue Asbestus.

Fibrous, asbestus-like; fibers long but delicate, and easily separable. Also massive or earthy. Cleavage: prismatic, 56°. H. = 4. G. = 3·20–3·30. Luster silky; dull. Color and streak lavender-blue or leek green. Opaque. Fibers somewhat elastic. Pleochroism: c green, b violet, a blue. Optically +. Extinction-angle on b, inclined 18° to 20° with $\dot{c}$. $2E = 95°$ approx. $\gamma - \alpha = 0·025$.

Comp.—$Na\overset{III}{Fe}(SiO_3)_2.FeSiO_3$ (nearly) = Silica 49·6, iron sesquioxide 22·0, iron protoxide 19·8, soda 8·6 = 100.

Magnesium and calcium replace part of the ferrous iron, and hydrogen part of the sodium.

Pyr., etc.—In the closed tube yields a small amount of alkaline water. B.B. fuses easily with intumescence to a black magnetic glass, coloring the flame yellow (soda). With the fluxes gives reactions for iron. Unacted upon by acids.

Obs.—Occurs in South Africa, in Griqualand-West, north of the Orange river, in a range of quartzose schists called the Asbestos Mountains. In a micaceous porphyry near Framont, in the Vosges. At Golling in Salzburg. In the U. S., at Beacon Pole Hill, near Cumberland, R. I. Emerald Mine, Buckingham, and Perkin's Mill, Templeton, Ottawa Co., Ontario, Canada.

Abriachanite is an earthy amorphous form occurring in the Abriachan district, near Loch Ness, Scotland. Crocidolite is named from κροκίς, *woof*, in allusion to its fibrous structure.

The South African mineral is largely altered by both oxidation of the iron and infiltration of silica, resulting in a compact siliceous stone of delicate fibrous structure, chatoyant luster, and bright yellow to brown color, popularly called *tiger-eye* (also cat's-eye and Faserquarz, Tigerauge, Falkenauge (bluish var.) *Germ.*). Many varieties occur forming transitions from the original blue mineral to the final product; also varieties depending upon the extent to which the original mineral has penetrated the quartz.

ARFVEDSONITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c} = 0·5569 : 1 : 0·2978$; $\beta = 73° 2'$.

Crystals long prisms, often tabular ‖ *b*, but seldom distinctly terminated; angles near those of amphibole; also in prismatic aggregates. Twins: tw.pl. *a*.

Cleavage: prismatic, perfect; *b* less perfect. Fracture uneven. Brittle. H. = 6. G. = 3·44–3·45. Luster vitreous. Color pure black; in thin scales deep green. Streak deep bluish gray. Opaque except in thin splinters. Pleochroism strongly marked: c deep greenish blue, b lavender, a pale greenish yellow. Absorption c > b > a; sections ‖ *a* are deep greenish blue, ‖ *b* olive-green. $\beta = 1·707$; $\gamma - \alpha = 0·027$. Extinction-angle on *b*, with $\acute{c}$, = 14°.

Comp.—A slightly basic metasilicate of sodium, calcium, and ferrous iron chiefly; an analysis by Lorenzen gives:

	G.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	
Kangerdluarsuk	3·44	43·85	4·45	3·80	33·43	0·45	0·81	4·65	8·15	1·06	0·15	= 100·80

The supposed arfvedsonite from Greenland analyzed by von Kobell, Rbg., etc., has been shown to be ægirite; that from Pike's Peak, Colorado, analyzed by Koenig, has been referred to riebeckite.

Pyr., etc.—B.B. fuses at 2 with intumescence to a black magnetic globule; colors the flame yellow (soda); with the fluxes gives reactions for iron and manganese. Not acted upon by acids.

Obs.—Arfvedsonite and amphiboles of similar character, containing much iron and soda, are common constituents of certain igneous rock which are rich in alkalies, as nephelite-syenite, phonolite, etc. Large and distinct crystals are found only in the pegmatite veins in such rocks, as at Kangerdluarsuk, Greenland, where the associated minerals are sodalite, eudialyte, feldspar, etc. Arfvedsonite occurs also in the nephelite-syenites and related rocks of the Christiania region in southern Norway; on the Kola peninsula in Russian Lapland; Dungannon township, Ontario; Trans Pecos district, Texas. The related brownish pleochroic amphiboles (cf. barkevikite) occur in similar rocks at Montreal, Canada; Red Hill, New Hampshire; Salem, Mass.; Magnet Cove, Ark.; Black Hills, So. Dakota; Square Butte, Montana, etc.

Crossite is a soda-amphibole near arfvedsonite (7·62Na_2O) from a rock in the neighborhood of San Francisco.

BARKEVIKITE. An amphibole near arfvedsonite but more basic. In prismatic crystals. Cleavage: prismatic (55° 44⅓'). G. = 3·428. Color deep velvet-black. Pleochroism marked, colors brownish. Extinction-angle with $\acute{c}$ on *b* = 12⅓°. Occurs at the wöhlerite locality near Barkevik, on the Langesund fiord, and elsewhere in southern Norway.

Ænigmatite. Cossyrite. Essentially a titano-silicate of ferrous iron and sodium, but containing also aluminium and ferric iron. In prismatic triclinic crystals. Cleavage: prismatic, distinct (66°). G. = 3·74–3·80. Color black. Ænigmatite is from the sodalite-syenite of Tunugdliarfik and Kangerdluarsuk, Greenland. *Cossyrite* occurs in minute crystals embedded in the liparite lavas of the island Pantellaria (ancient name Cossyra).

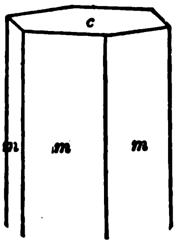
BERYL.

Hexagonal. Axis $\acute{c} = 0·4989$.

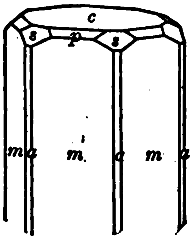
Crystals usually long prismatic, often striated vertically, rarely transversely; distinct terminations exceptional. Occasionally in large masses, coarse columnar or granular to compact.

Cleavage: *c* imperfect and indistinct. Fracture conchoidal to uneven. Brittle. H. = 7·5–8. G. = 2·63–2·80; usually 2·69–2·70. Luster vitreous, sometime resinous. Colors emerald-green, pale green, passing into light blue, yellow and white; also pale rose-red. Streak white. Transparent to subtranslucent. Dichroism more or less distinct. Optically —. Birefringence low. Often abnormally biaxial. $\omega = 1{\cdot}5820$, $\epsilon = 1{\cdot}5765$ aquamarine.

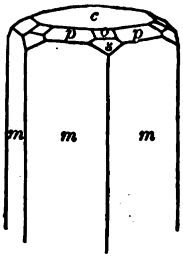
793.



794.



795.



cp, $0001 \wedge 10\bar{1}1 = 29° \, 56\frac{1}{2}'$. cs, $0001 \wedge 11\bar{2}1 = 44° \, 56'$.
co, $0001 \wedge 11\bar{2}2 = 26° \, 31'$. pp', $10\bar{1}1 \wedge 01\bar{1}1 = 28° \, 54\frac{1}{2}'$.

Var.—1. *Emerald.* Color bright emerald-green, due to the presence of a little chromium; highly prized as a gem when clear and free from flaws.

2. *Ordinary; Beryl.* Generally in hexagonal prisms, often coarse and large; green the common color. The principal kinds are: (*a*) colorless; (*b*) bluish green, called *aquamarine;* (*c*) apple-green; (*d*) greenish yellow to iron-yellow and honey-yellow; sometimes a clear bright yellow as in the *golden beryl;* (*e*) pale yellowish green; (*f*) clear sapphire-blue; (*g*) pale sky-blue; (*h*) the pale violet or reddish; (*i*) the opaque brownish yellow, of waxy or greasy luster. The *oriental emerald* of jewelry is emerald-colored sapphire.

Comp.—$Be_3Al_2(SiO_3)_6$ or $3BeO.Al_2O_3.6SiO_2$ = Silica 67·0, alumina 19·0, glucina 14·0 = 100.

Alkalies (Na_2O, Li_2O, Cs_2O) are sometimes present replacing the beryllium, from 0·25 to 5 p. c.; also chemically combined water, including which the formula becomes $H_2Be_6Al_4Si_{12}O_{37}$.

Pyr., etc.—B.B. alone, unchanged or, if clear, becomes milky white and clouded; at a high temperature the edges are rounded, and ultimately a vesicular scoria is formed. Fusibility = 5·5, but somewhat lower for beryls rich in alkalies. Glass with borax, clear and colorless for beryl, a fine green for emerald. Unacted upon by acids.

Diff.—Characterized by its green or greenish-blue color, glassy luster and hexagonal form; rarely massive, then easily mistaken for quartz. Distinguished from apatite by its hardness, not being scratched by a knife, also harder than green tourmaline; from chrysoberyl by its form; from euclase and topaz by its imperfect cleavage.

Obs.—Beryl is a common accessory mineral in granite veins, especially in those of a pegmatitic character. Emeralds occur in clay slate, in isolated crystals or in nests, near Muso, etc., 75 m. N.N.E. of Bogotà, Colombia. Emeralds of less beauty, but larger, occur in Siberia, on the river Tokovoya, N. of Ekaterinburg, embedded in mica schist. Emeralds of large size, though not of uniform color or free from flaws, have been obtained in Alexander Co., N. C.

Transparent beryls are found in Siberia, India and Brazil. In Siberia they occur at Mursinka and Shaitanka, near Ekaterinburg; near Miask with topaz; in the mountains of Adun-Chalon with topaz, in E. Siberia. Beautiful crystals also occur at Elba; the tin mines of Ehrenfriedersdorf in Saxony, and Schlackenwald in Bohemia. Other localities are the Mourne Mts., Ireland; yellowish green at Rubislaw, near Aberdeen, Scotland (*davidsonite*); Limoges in France; Finbo and Broddbo in Sweden; Tamela in Finland; Pfitsch-Joch, Tyrol; Bodenmais and Rabenstein in Bavaria; in New South Wales.

In the United States, beryls of gigantic dimensions have been found in *N. Hamp.*, at Acworth and Grafton, and in *Mass.*, at Royalston. In *Maine*, at Albany; Norway; Bethel; at Hebron, a cæsium beryl (Cs_2O, 3·60 p. c.), associated with pollucite; in Paris, with black tourmaline; at Topsham, pale green or yellowish. In *Mass.*, at Barre; at Goshen (*goshenite*), and at Chesterfield. In *Conn.*, at Haddam, and at the Middletown and Portland feldspar quarries; at New Milford, of a clear golden yellow to dark amber color; Branchville. In

Penn., at Leiperville and Chester; at Mineral Hill. In *Virginia*, at Amelia Court-House, sometimes white. In *N. Carolina*, in Alexander Co., near Stony Point, fine emeralds; in Mitchell Co.: Morganton, Burke Co., and elsewhere. In *Alabama*, Coosa Co., of a light yellow color. In *Colorado*, near the summit of Mt. Antero, beautiful aquamarines. In *S. Dakota*, in the Black Hills in large crystals.

Eudialyte. Essentially a metasilicate of Zr,Fe(Mn),Ca,Na, etc. In red to brown tabular or rhombohedral crystals; also massive. H. = 5–5·5. G. = 2·9–3·0. Optically +. From Kangerdluarsuk, West Greenland, etc., with arfvedsonite and sodalite; at Lujaor on the Kola peninsula, Russian Lapland, in elæolite-syenite, there forming a main constituent of the rock-mass. *Eucolite*, from islands of the Langesund fiord in Norway, is similar (but optically —). Eudialyte and eucolite also occur at Magnet Cove, in Arkansas, of a rich crimson to peach-blossom red color, in feldspar, with elæolite and ægirite.

Elpidite. $Na_2O.ZrO_2.6SiO_2.3H_2O$.—Massive, fibrous. G. = 2·54. Southern Greenland.

The following are rare species of complex composition, all from the Langesund fiord region of southern Norway.

Catapleiite. $H_4(Na_2,Ca)ZrSi_3O_{11}$. In thin tabular hexagonal prisms. H. = 6. G. = 2·8. Color light yellow to yellowish brown. *Natron-catapleiite*, or soda-catapleiite, contains only sodium; color blue to gray and white; on heating the blue color disappears.

Cappelenite. A boro-silicate of yttrium and barium. In greenish-brown hexagonal crystals.

Melanocerite. A fluo-silicate of the cerium and yttrium metals and calcium chiefly (also B, Ta, etc.). In brown to black tabular rhombohedral crystals.

Caryocerite. Near melanocerite, containing ThO_2.

STEENSTRUPINE (from Greenland) is allied to the two last-named species.

Tritomite. A fluo-silicate of thorium, the cerium and yttrium metals and calcium, with boron. In dark brown crystals of acute triangular pyramidal form.

The following are also from the same region:

Leucophanite. $Na(BeF)Ca(SiO_3)_2$. In glassy greenish tabular crystals (orthorhombic-sphenoidal). H. = 4. G. = 2·96.

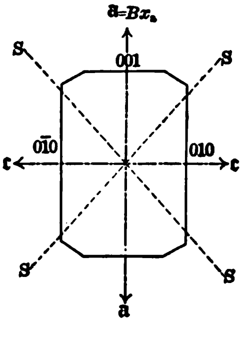
Meliphanite. A fluo-silicate of beryllium, calcium, and sodium near leucophanite. In low square pyramids (tetragonal). Color yellow. H. = 5–5·5. G. = 3·01.

IOLITE. Cordierite. Dichroite.

Orthorhombic. Axes $\breve{a} : \bar{b} : \acute{c} = 0·5871 : 1 : 0·5585$.

Twins: tw. pl. *m*, also *d* (130), both yielding pseudo-hexagonal forms. Habit short prismatic ($mm''' = 60° 50'$) (Fig. 299, p. 94). As embedded grains; also massive, compact.

796.



Cleavage: *b* distinct; *a* and *c* indistinct. Crystals often show a lamellar structure ‖ *c*, especially when slightly altered. Fracture subconchoidal. Brittle. H. = 7–7·5. G. = 2·60–2·66. Luster vitreous. Color various shades of blue, light or dark, smoky blue. Transparent to translucent. Pleochroism strongly marked except in thin sections. Axial colors variable. Thus:

Bodenmais $\mathfrak{c} (= \bar{b})$ dark Berlin-blue $\mathfrak{b} (= \breve{a})$ light Berlin-blue $\mathfrak{a} (= \acute{c})$ yellowish white

Absorption $\mathfrak{c} (\bar{b}) > \mathfrak{b} (\breve{a}) > \mathfrak{a} (\acute{c})$. Pleochroic halos common, often bright yellow; best seen in sections ‖ $\acute{c}$. Exhibits idiophanous figures. Optically —. Ax. pl. ‖ *a*. Bx. ⊥ *c*. Dispersion feeble, $\rho < v$. 2V = 70° 23′ (also 40° to 84°). $\beta_y = 1·549$; $\gamma - \alpha = 0·008$.

Comp.—$H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$ or $H_2O.4(Mg,FeO).4Al_2O_3.10SiO_2$. If Mg : Fe = 7 : 2, the percentage composition is: Silica 49·4, alumina 33·6, iron protoxide 5·3, magnesia 10·2, water 1·5 = 100. Ferrous iron replaces part of the magnesium. Calcium is also present in small amount.

Pyr., etc.—B.B. loses transparency and fuses at 5–5·5. Only partially decomposed by acids. Decomposed on fusion with alkaline carbonates.

Diff.—Characterized by its vitreous luster, color and pleochroism; fusible on the edges unlike quartz; less hard than sapphire.

Recognized in thin sections by lack of color; low refraction and low interference-colors; it is very similar to quartz, but distinguished by its biaxial character; in volcanic rocks commonly shows distinct crystal outlines and a twinning of three individuals like aragonite. In the gneisses, etc., it is in formless grains, but the common occurrence of inclusions, especially of sillimanite needles, the pleochroic halos of a yellow color around small inclusions, particularly zircons, and the constant tendency to alteration to micaceous pinite seen along cleavages, help to distinguish it.

Obs.—Occurs in granite, gneiss (*cordierite-gneiss*), hornblendic, chloritic and talcose schist, and allied rocks, with quartz, orthoclase or albite, tourmaline, hornblende, andalusite, sillimanite, garnet, and sometimes beryl. Less commonly in or connected with igneous rocks, thus formed directly from the magma, as in andesite, etc.; also in ejected masses (in fragments of older rocks); further formed as a contact-mineral in connection with eruptive dikes, as in slates adjoining granite.

Occurs at Bodenmais, Bavaria, in granite, with pyrrhotite, etc.; Orijärvi, in Finland (*steinheilite*); Tunaberg, in Sweden; in colorless crystals from Brazil; Ceylon affords a transparent variety, the *saphir d'eau* of jewelers.

In the U. S., at Haddam, Conn., associated with tourmaline in a granitic vein in gneiss. At Brimfield, Mass.; at Richmond, N. H.

Named *Iolite* from ἴον, *violet*, and λίθος, *stone*; *Dichroite* (from δίχροος, *two-colored*), from its dichroism; *Cordierite*, after Cordier, the French geologist (1777–1861).

The alteration of iolite takes place so readily by ordinary exposure, that the mineral is most commonly found in an altered state, or enclosed in the altered iolite. This change may be a simple hydration; or a removal of part of the protoxide bases by carbon dioxide; or the introduction of oxide of iron; or of alkalies, forming pinite and mica. The first step in the change consists in a division of the prisms of iolite into plates parallel to the base, and a pearly foliation of the surfaces of these plates; with a change of color to grayish green and greenish gray, and sometimes brownish gray. As the alteration proceeds, the foliation becomes more complete; afterward it may be lost. The mineral in this altered condition has many names: as *hydrous iolite* (incl. *bonsdorffite* and *auralite*) from Åbo, Finland; *fahlunite* from Falun, Sweden, also *pyrargillite* from Helsingfors; *esmarkite* and *praseolite* from near Brevik, Norway, also *raumite* from Raumo, Finland, and *peplolite* from Ramsberg, Sweden; *chlorophyllite* from Unity, Me.; *aspasiolite*; and *polychroilite* from Kragerö. There are further alkaline kinds, as *pinite*, *cataspilite*, *gigantolite*, *iberite*, belonging to the Mica Group.

The following are rare lead and barium silicates:

Barysilite. $Pb_3Si_2O_7$. In embedded masses with curved lamellar structure. Cleavage: basal. H. = 3. G. = 6·11–6·55. Color white; tarnishing on exposure. From the Harstig mine, Pajsberg, Sweden.

Ganomalite. $Pb_3Si_2O_7.(Ca,Mn)_2SiO_4$. In prismatic crystals (tetragonal); also massive, granular. H. = 3. G. = 5·74. Colorless to gray. From Långban, Sweden; also Jakobsberg.

Hyalotekite. Approximately $(Pb,Ba,Ca),B_2(SiO_3)_{12}$. Massive; coarsely crystalline. H. = 5–5·5. G. = 3·81. Color white to pearly gray. From Långban, Sweden.

Barylite. $Ba_4Al_4Si_7O_{24}$. In groups of colorless prismatic crystals. H. = 7. G. = 4·03. Luster greasy. Occurs with hedyphane in crystalline limestone at Långban, Sweden.

Roeblingite. $5(H_2CaSiO_4).2(CaPbSO_4)$. In dense, white, compact, crystalline masses. H. = 3. G. = 3·433. From Franklin Furnace, N. J.

III. Orthosilicates. R_2SiO_4.

Salts of Orthosilicic Acid, H_4SiO_4; characterized by an oxygen ratio of 1 : 1 for silicon to bases.

The following list includes the more prominent groups among the Orthosilicates.

A number of basic orthosilicates are here included, which yield water upon ignition; also others which are more or less basic than a normal orthosilicate, but which are of necessity introduced here in the classification, because of their relationship to other normal salts. The MICA GROUP is so closely related to many Hydrous Silicates that (with also Talc, Kaolinite, and some others) it is described later with them.

Nephelite Group. Hexagonal.
Sodalite Group. Isometric.
Helvite Group. Isometric-tetrahedral.
Garnet Group. Isometric.
Chrysolite Group. Orthorhombic.
Phenacite Group. Tri-rhombohedral.
Scapolite Group. Tetragonal-pyramidal.
Zircon Group. Tetragonal.
Danburite Group. Orthorhombic.
Datolite Group. Monoclinic.
Epidote Group. Monoclinic.

Nephelite Group. Hexagonal.

Typical formula $\overset{\text{I}}{\text{R}}\text{AlSiO}_4$.

Nephelite	$K_2Na_6Al_8Si_9O_{34}$		$\dot{c} = 0{\cdot}8389$
Soda-nephelite (artif.)	$NaAlSiO_4$		
Eucryptite	$LiAlSiO_4$	**Kaliophilite**	$KAlSiO_4$
Cancrinite	$H_6Na_6Ca(NaCO_3)_2Al_8(SiO_4)_9$		$2\dot{c} = 0{\cdot}8448$
Microsommite	$(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4$		$2\dot{c} = 0{\cdot}8367$

The species of the NEPHELITE GROUP are hexagonal in crystallization and have in part the typical orthosilicate formula $\overset{\text{I}}{\text{R}}\text{AlSiO}_4$. From this formula nephelite itself deviates somewhat, though an artificial soda-nephelite, $NaAlSiO_4$, conforms to it. The species Cancrinite and Microsommite are related in form and also in composition, though in the latter respect somewhat complex. They serve to connect this group with the sodalite group following.

NEPHELITE. Nepheline.

Hexagonal-hemimorphic (p. 73). Axis $\dot{c} = 0{\cdot}83893$.

In thick six- or twelve-sided prisms with plane or modified summits. Also massive compact, and in embedded grains; structure sometimes thin columnar.

Cleavage: *m* distinct; *c* imperfect. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 2·55–2·65. Luster vitreous to greasy; a little opalescent in some varieties. Colorless, white, or yellowish; also when massive, dark green, greenish or bluish gray, brownish red and brick-red. Transparent to opaque. Optically —. Indices: $\omega_y = 1{\cdot}542$, $\epsilon_y = 1{\cdot}538$.

Var.—1. ***Nephelite. Glassy.***—Usually in small glassy crystals or grains, transparent with vitreous luster, first found on Mte. Somma. Characteristic particularly of younger eruptive rocks and lavas. 2. ***Elæolite.***—In large coarse crystals, or more commonly massive, with a greasy luster, and reddish, greenish, brownish or gray in color. Usually clouded by minute inclusions. Characteristic of granular crystalline rocks, syenite, etc.

Comp.—$\overset{I}{R}_8Al_8Si_9O_{34}$; if $\overset{I}{R}$ = Na : K = 3 : 1, this is equivalent to $3Na_2O.K_2O.4Al_2O_3.9SiO_2$ = Silica 44·0, alumina 33·2, soda 15·1, potash 7·7 = 100. In most analyses Na : K = 4 : 1 or 5 : 1.

Synthetic experiments, yielding crystals like nephelite with the composition $NaAlSiO_4$, lead to the conclusion that a natural soda-nephelite would be an orthosilicate with this formula, while the higher silica in the potash varieties may be explained by the presence, in molecular combination, of $KAlSi_2O_6$ or $K_2O.Al_2O_3.4SiO_2$ (= leucite). The other species of the group are normal orthosilicates, viz., eucryptite $LiAlSiO_4$, and kaliophilite, $KAlSiO_4$.

Pyr., etc.—B.B. fuses quietly at 3·5 to a colorless glass. Gelatinizes with acids.

Diff.—Distinguished by its gelatinizing with acids from scapolite and feldspar, as also from apatite, from which it differs too in its greater hardness. Massive varieties have a characteristic greasy luster.

Recognized in thin sections by its low refraction; very low interference-colors, which scarcely rise to gray; parallel extinction when in crystals; faint negative uniaxial cross yielded by basal sections in converging light. The negative character is best told by aid of the selenite plate (see p. 201). Micro-chemical tests serve to distinguish non-characteristic particles from similar ones of alkali feldspar; the section is treated with dilute acid, and the resultant gelatinous silica, which coats the nephelite particles, stained with eosine or other dye.

Obs.—Nephelite is rather widely distributed (as shown by the microscopic study of rocks) in igneous rocks as the product of crystallization of a magma rich in soda and at the same time low in silica (which last prevents the soda from being used up in the formation of albite). It is thus an essential component of the nephelite-syenites and phonolites where it is associated with alkali feldspars chiefly. It is also a constituent of more basic augitic rocks such as nephelinite, nephelite-basalts, nephelite-tephrites, theralite, etc., most of which are volcanic in origin. The variety *elæolite* is associated with the granular plutonic rocks, while the name *nephelite* was originally used for the fresh glassy crystals of the modern lavas; the terms have in this sense the same relative significance as orthoclase and sanidine. Modern usage, however, tends to drop the name *elæolite*.

The original *nephelite* occurs in crystals in the older lavas of Mte. Somma, with mica, vesuvianite, etc.; at Capo di Bove, near Rome; in the basalt of Katzenbuckel, near Heidelberg; Aussig in Bohemia; Löbau in Saxony. Occurs also in massive forms and large coarse crystals (*elæolite*) in the nephelite-syenites of Southern Norway, especially along the Langesund fiord; similarly in west Greenland; the peninsula of Kola; Miask in the Ilmen Mts. (in the rock *miascite*); Sierra Monchique, Portugal (in the rock *foyaite*); Ditró, Hungary (in the rock *ditroite*); Pousac, France; Brazil; South Africa.

Elæolite occurs massive and crystallized at Litchfield, Me., with cancrinite; Salem, Mass.; Red Hill, N. H.; in the Ozark Mts., near Magnet Cove, Arkansas; elæolite-syenite is also found near Beemersville, northern N. J.; near Montreal, Canada; at Dungannon township, Ontario, in enormous crystals. Nephelite rocks also occur at various points, as the Transpecos distr., Texas; Pilot Butte, Texas; also in western N. America, as in Colorado at Cripple Creek; in Montana, in the Crazy Mts., the Highwood, Bearpaw and Judith Mts; Black Hills in So. Dakota; Ice River, British Columbia.

Named *nephelite* from νεφέλη, *a cloud*, in allusion to its becoming cloudy when immersed in strong acid; *elæolite* is from ἐλαίον, *oil*, in allusion to its greasy luster.

Gieseckite is a pseudomorph after nephelite. It occurs in Greenland in six-sided greenish-gray prisms of greasy luster; also at Diana in Lewis Co., N. Y. *Dysyntribite* from Diana is similar to gieseckite, as is also *liebenerite*, from the valley of Fleims, in Tyrol. See further PINITE under the MICA GROUP.

Eucryptite. $LiAlSiO_4$. In symmetrically arranged crystals (hexagonal), embedded in albite and derived from the alteration of spodumene at Branchville, Conn. (see Fig. 474, p. 141). G. = 2·667. Colorless or white.

Kaliophilite. $KAlSiO_4$. Phacellite. Phacelite. Facellite. In bundles of slender acicular crystals (hexagonal), also in fine threads, cobweb-like. H. = 6. G. = 2·493–2·602. Colorless. Occurs in ejected masses at Mte. Somma.

CANCRINITE.

Hexagonal. Axis $\dot{c} = 0{\cdot}4224$; and $mp = 64°$, $pp' = 25° \ 58'$. Rarely in prismatic crystals with a low terminal pyramid. Usually massive.

Cleavage: prismatic (*m*) perfect; *a* less so. H. = 5–6. G. = 2·42–2·5. Color white, gray, yellow, green, blue, reddish. Streak uncolored. Luster subvitreous, or a little pearly or greasy. Transparent to translucent. Optically uniaxial, negative.

Comp.—$H_6Na_6Ca(NaCO_3)_2Al_8(SiO_4)_9$ or $3H_2O.4Na_2O.CaO.4Al_2O_3.9SiO_2.2CO_2$ = Silica 38·7, carbon dioxide 6·3, alumina 29·3, lime 4·0, soda 17·8, water 3·9 = 100.

Pyr., etc.—In the closed tube gives water. B.B. loses color, and fuses (F. = 2) with intumescence to a white blebby glass, the very easy fusibility distinguishing it readily from nephelite. Effervesces with hydrochloric acid, and forms a jelly on heating, but not before.

Diff.—Recognized in thin sections by its low refraction; quite high interference-colors and negative uniaxial character. Its common association with nephelite, sodalite, etc., are valuable characteristics. Evolution of CO_2 with acid distinguishes it from all other minerals except the carbonates, which show much higher interference-colors.

Obs.—Cancrinite occurs only in igneous rocks of the nephelite-syenite and related rock groups. It is in part believed to be original, i.e., formed directly from the molten magma; in part held to be secondary and formed at the expense of nephelite by infiltrating waters holding calcium carbonate in solution. Prominent localities are Miask in the Ilmen Mts., in coarse-grained nephelite-syenite; similarly at Barkevik and other localities on the Langesund fiord in southern Norway; in the parish of Kuolajärvi in northern Finland (where, associated with orthoclase, ægirite and nephelite, it composes a mass of cancrinite-syenite); at Ditró, Transylvania, etc.; in nephelite-syenite of Särna and Alnö in Sweden, and in Brazil; also in small amount as an occasional accessory component of many phonolitic rocks at various localities.

In the United States at Litchfield and West Gardiner, Me., with elæolite and blue sodalite. Named after Count Cancrin, Russian Minister of Finance.

Microsommite. Near cancrinite; perhaps $(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4)$. In minute colorless prismatic crystals (hexagonal). From Vesuvius (Monte Somma). H. = 6. G. = 2·42–2·53.

DAVYNE is in part at least microsommite. From Mte. Somma.

Sodalite Group. Isometric.

Sodalite	$Na_4(AlCl)Al_2(SiO_4)_3$
Haüynite	$(Na_2,Ca)_2(NaSO_4.Al)Al_2(SiO_4)_3$
Noselite	$Na_4(NaSO_4.Al)Al_2(SiO_4)_3$
Lazurite	$Na_4(NaS_3.Al)Al_2(SiO_4)_3$

The species of the Sodalite Group are isometric in crystallization and perhaps tetrahedral like the following group. In composition they are peculiar (like cancrinite of the preceding group) in containing radicals with Cl, SO and S, which are elements usually absent in the silicates. These are shown in the formulas written above in the form suggested by Brögger, who shows that this group and the one following may be included with the garnets in a broad group characterized by isometric crystallization and a close resemblance in composition. See further under the GARNET GROUP proper, p. 414.

The formulas are also often written as if the compound consisted of a silicate and chloride (sulphate, sulphide)—thus for sodalite, $3NaAlSiO_4 + NaCl$, etc.

SODALITE.

Isometric, perhaps tetrahedral. Common form the dodecahedron. Twins: tw. pl. *o*, forming hexagonal prisms by elongation in the direction of an octahedral axis (Fig. 368, p. 123). Also massive, in embedded grains; in concentric nodules resembling chalcedony, formed from elæolite.

Cleavage: dodecahedral, more or less distinct. Fracture conchoidal to uneven. Brittle. H. = 5·5–6. G. = 2·14–2·30. Luster vitreous, sometimes inclining to greasy. Color gray, greenish, yellowish, white; sometimes blue, lavender-blue, light red. Transparent to translucent. Streak uncolored. $n_\gamma = 1{\cdot}4827$ Na.

Comp.—$Na_4(AlCl)Al_2(SiO_4)_3$ = Silica 37·2, alumina 31·6, soda 25·6, chlorine 7·3 = 101·7, deduct (O = 2Cl) 1·7 = 100. Potassium replaces a small part of the sodium. The formula may also be written $3NaAlSiO_4 + NaCl$.

Pyr., etc.—In the closed tube the blue varieties become white and opaque. B.B. fuses with intumescence, at 8·5–4, to a colorless glass. Decomposed by hydrochloric acid, with separation of gelatinous silica.

Diff.—Recognized in thin sections by its very low refraction, isotropic character and lack of good cleavage; also, in most cases, by its lack of color. Distinguished from much analcite, leucite and haüynite by chemical tests alone; dissolving the mineral in dilute nitric acid and testing for chlorine is the simplest and best.

Obs.—Sodalite occurs only in igneous rocks of the nephelite-syenite and related rock groups, either directly, as is commonly the case, as a product of the crystallization of a magma rich in soda; also as a product associated with enclosed masses and bombs ejected with such magmas in the form of lava, as at Vesuvius. Often associated with nephelite (or elæolite), cancrinite and eudialyte. With sanidine it form a *sodalite-trachyte* at Scarrupata in Ischia, in crystals. In Sicily, Val di Noto, with nephelite and analcite. At Vesuvius, in bombs on Monte Somma in white, translucent, dodecahedral crystals; massive and of a gray color at the Kaiserstuhl; also near Lake Laach. At Ditró, Transylvania, in an elæolite-syenite. In the foyaite of southern Portugal. At Miask, in the Ilmen Mts.; in the augite-syenite of the Langesund-fiord region in Norway. Further in West Greenland in sodalite-syenite; the peninsula of Kola.

A blue massive variety occurs at Litchfield and West Gardiner, Me. Occurs in the theralite of the Crazy Mts., Montana; also at Square Butte, Highwood Mts., and in the Bearpaw Mts., in tinguaite. Occurs also in the elæolite-syenite of Brome, Brome Co., and of Montreal and Belœil, province of Quebec; at Dungannon, Ontario, in large blue masses and in small pale pink crystals.

HAÜYNITE. Haüyne.

Isometric. Sometimes in dodecahedrons, octahedrons, etc.

Twins: tw. pl. *e*; contact-twins, also polysynthetic; penetration-twins (Fig. 367, p. 123). Commonly in rounded grains, often looking like crystals with fused surfaces.

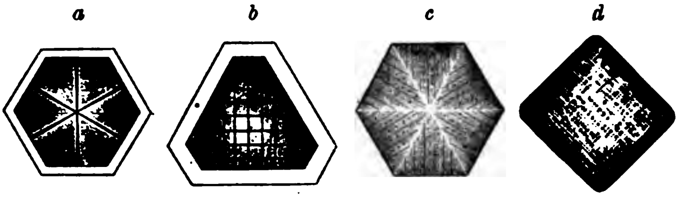
Cleavage: dodecahedral, rather distinct. Fracture flat conchoidal to uneven. Brittle. H. = 5·5–6. G. = 2·4–2·5. Luster vitreous, to somewhat greasy. Color bright blue, sky-blue, greenish blue; asparagus-green, red, yellow. Streak slightly bluish to colorless. Subtransparent to translucent; often enclosing symmetrically arranged inclusions (Fig. 797). $n_\gamma = 1{\cdot}4961$.

Comp.—$Na_2Ca(NaSO_4.Al)Al_2(SiO_4)_3$. This is analogous to the garnet formula (Brögger) where the place of the R_3 is taken by Na_2, Ca and the group Na–O–SO_2–O–Al. The percentage composition is: Silica 32·0, sulphur trioxide 14·2, alumina 27·2, lime 10·0, soda 16·6 = 100. The ratio of Na_2 : Ca also varies from 3 : 2; potassium may be present in small amount. The formula may also be written $2(Na_2,Ca)Al_2(SiO_4)_2 + (Na_2,Ca)SO_4$.

Pyr., etc.—In the closed tube retains its color. B.B. in the forceps fuses at 4·5 to a white glass. Fused with soda on charcoal affords a sulphide, which blackens silver. Decomposed by hydrochloric acid with separation of gelatinous silica.

Obs.—Common in certain igneous rocks, thus in haüynophyre, in phonolite, tephrite; very commonly associated with nephelite and leucite. Occurs in the Vesuvian lavas, on Mte. Somma; at Melfi, on Mt. Vultur, Naples; in the lavas of the Campagna, Rome, also in the peperino near Albano; at Niedermendig, in the Eifel; the phonolites of Hohentwiel.

797.



Section of crystals of haüynite (after Möhl).

Noselite or Nosean. Near haüynite, but contains little or no lime. Color grayish, bluish, brownish; sometimes nearly opaque from the presence of inclusions (cf. Fig. 797). Not uncommon in phonolite. At Andernach, the Laacher See, and elsewhere.

LAZURITE. Lapis-Lazuli. Lasurite.

Isometric. In cubes and dodecahedrons. Commonly massive, compact.

Cleavage: dodecahedral, imperfect. Fracture uneven. H. = 5–5·5. G. = 2·38–2·45. Luster vitreous. Color rich Berlin-blue or azure-blue, violet-blue, greenish blue. Translucent.

Comp.—Essentially $Na_4(NaS_3.Al)Al_2(SiO_4)_3$ (Brögger), but containing also in molecular combination haüynite and sodalite. The percentage composition of this ultramarine compound is as follows: Silica 31·7, alumina 26·9, soda 27·3, sulphur 16·9 = 102·9, or deduct (O = S) 2·9 = 100.

The heterogeneous character of what had long passed as a simple mineral under the name Lapis-lazuli was shown by Fischer (1869), Zirkel (1873), and more fully by Vogelsang (1873). The ordinary natural *lapis lazuli* (Lasurstein) is shown by Brögger and Bäckström to contain lazurite or haüynite (sometimes changed to a zeolite), a diopside free from iron, amphibole (koksharovite), mica (muscovite), calcite, pyrite; also in some varieties in relatively small amount scapolite, plagioclase, orthoclase (microperthite?), apatite, titanite, zircon, and an undetermined mineral optically + and probably uniaxial. Regarded by Brögger as a result of contact metamorphism in limestone.

Pyr., etc.—Heated in the closed tube gives off some moisture; the variety from Chili glows with a beetle-green light, but the color of the mineral remains blue on cooling. Fuses easily (3) with intumescence to a white glass. Decomposed by hydrochloric acid, with separation of gelatinous silica and evolution of hydrogen sulphide.

Obs.—Occurs in Badakshan in the valley of the Kokcha, a branch of the Oxus, a few miles above Firgamu. Also at the south end of L. Baikal. Further, in Chili in the Andes of Ovalle. In ejected masses at Monte Somma, rare.

The richly colored varieties of lapis lazuli are highly esteemed for costly vases and ornamental furniture; also employed in the manufacture of mosaics; and when powdered constitutes the rich and durable paint called *ultramarine*. This has been replaced, however, by artificial ultramarine, now an important commercial product.

Helvite Group. Isometric-tetrahedral.

Helvite	$(Mn.Fe)_2(Mn_2S)Be_3(SiO_4)_3$
Danalite	$(Fe,Zn,Mn)_2((Zn,Fe)_2S)Be_3(SiO_4)_3$
Eulytite	$Bi_4(SiO_4)_3$
Zunyite	$(Al(OH,F,Cl)_2)_6Al_2(SiO_4)_3$

The Helvite Group includes several rare species, isometric-tetrahedral in crystallization and in composition related to the species of the SODALITE GROUP and also to those of the GARNET GROUP which follows:

HELVITE.

Isometric-tetrahedral. Commonly in tetrahedral crystals; also in spherical masses.

Cleavage: octahedral in traces. Fracture uneven to conchoidal. Brittle. H. = 6–6·5. G. = 3·16–3·36. Luster vitreous, inclining to resinous. Color honey-yellow, inclining to yellowish brown, and siskin-green, reddish brown. Streak uncolored. Subtransparent. $n = 1{\cdot}739$. Pyroelectric.

Comp.—$(Be,Mn,Fe)_7Si_3O_{12}S$. This may be written $(Mn,Fe)_2(Mn_2S)Be_3(SiO_4)_3$ (Brögger), analogous to the Garnet Group, the bivalent group –Mn–S–Mn taking the place of a bivalent element, R, and 3Be corresponding to 2Al, cf. p. 415. Composition also written $3(Be,Mn,Fe)_2SiO_4.(Mn,Fe)S$.

Pyr., etc.—Fuses at 3 in R.F. with intumescence to a yellowish-brown opaque bead, becoming darker in R.F. With the fluxes gives the manganese reaction. Decomposed by hydrochloric acid, with evolution of hydrogen sulphide and separation of gelatinous silica.

Obs.—Occurs at Schwarzenberg and Breitenbrunn, in Saxony; at Kapnik, Hungary; also in the pegmatite veins of the augite-syenite of the Langesund fiord; in the Ilmen Mts. near Miask in pegmatite. In the U. S., with spessartite at the mica mines near Amelia Court-House, Amelia Co., Va.; etc. Named by Werner, in allusion to its yellow color, from ἥλιος, *the sun.*

Danalite. $(Be,Fe,Zn,Mn)_7Si_3O_{12}S$. In octahedrons; usually massive. H. = 5·5–6. G. = 3·427. Color flesh-red to gray. Occurs in small grains in the Rockport granite, Cape Ann, Mass.; at the iron mine at Bartlett, N. H.; El Paso Co., Colorado.

Eulytite. $Bi_4Si_3O_{12}$. Wismuthblende, Kieselwismuth *Germ.* Usually in minute tetrahedral crystals; also in spherical forms. H. = 4·5. G. = 6·106. Color dark hair-brown to grayish, straw-yellow, or colorless. Found with native bismuth near Schneeberg, Saxony; also at Johanngeorgenstadt in crystals on quartz.

Zunyite. A highly basic orthosilicate of aluminium, $(Al(OH,F,Cl)_2)_6Al_2Si_3O_{12}$. In minute transparent tetrahedrons. H. = 7. G. = 2·875. From the Zuñi mine, near Silverton, San Juan Co., and on Red Mountain, Ouray Co., Colorado.

---

4. Garnet Group. Isometric.

$$\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3, \text{ or } 3RO.R_2O_3.3SiO_2.$$

$$\overset{II}{R} = Ca,Mg,\overset{II}{Fe},\overset{II}{Mn}. \qquad \overset{III}{R} = Al,\overset{III}{Fe},Cr,\overset{III}{Ti}.$$

Garnet			
A. GROSSULARITE	$Ca_3Al_2(SiO_4)_3$	D. SPESSARTITE	$Mn_3Al_2(SiO_4)_3$
B. PYROPE	$Mg_3Al_2(SiO_4)_3$	E. ANDRADITE	$Ca_3Fe_2(SiO_4)_3$
C. ALMANDITE	$Fe_3Al_2(SiO_4)_3$	Also	$(Ca,Mg)_3Fe_2(SiO_4)_3$, $Ca_3Fe_2((Si,Ti)O_4)_3$
		F. UVAROVITE	$Ca_3Cr_2(SiO_4)_3$
Schorlomite	$Ca_3(Fe,Ti)_2((Si,Ti)O_4)_3$		

The GARNET GROUP includes a series of important sub-species included under the same specific name. They all crystallize in the normal group of the isometric system and are alike in habit, the dodecahedron and trapezohedron being the common forms. They have also the same general formula, and while the elements present differ widely, there are many intermediate varieties. Some of the garnets include titanium, replacing silicon, and thus they are connected with the rare species schorlomite, which probably also has the same general formula.

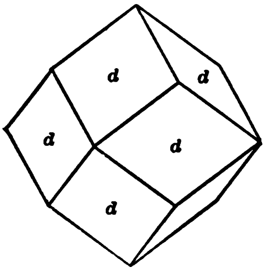
Closely related to the **Garnet Group** proper are the species of the Sodalite and Helvite Groups (p. 411, p. 413). All are characterized by isometric crystallization, and all are orthosilicates, with similar chemical structure. Thus the formula of the Garnet Group is $\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3$; to this Sodalite conforms if written $Na_4(AlCl)Al_2(SiO_4)_3$, where Na_4 and the bivalent radical AlCl are equivalent to R_3; similarly for Noselite (Haüynite) if the presence of the bivalent group $NaSO_4$–Al is assumed.

In the Helvite Group, which is characterized by the tetrahedral character of the species (perhaps true also of the Sodalites), the chemical relation is less close but probably exists, as exhibited by writing the formula of Helvite $(Mn,Fe)(Mn_2S)Be_3(SiO_4)_3$, where the bivalent group –S–Mn–S– enters, and 3Be may be regarded as taking the place of 2Al.

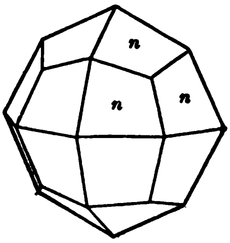
GARNET.

Isometric. The dodecahedron and trapezohedron, *n* (211), the common simple forms; also these in combination, or with the hexoctahedron *s* (321). Cubic and octahedral faces rare. Often in irregular embedded grains. Also massive; granular, coarse or fine, and sometimes friable; lamellar, lamellæ thick and bent. Sometimes compact, cryptocrystalline like nephrite.

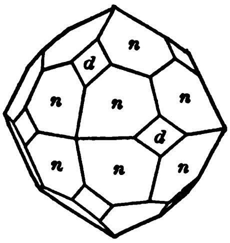
798.



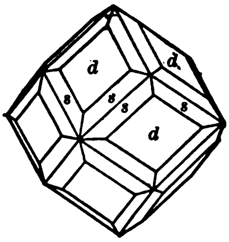
799.



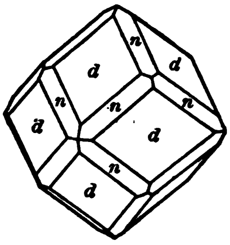
800.



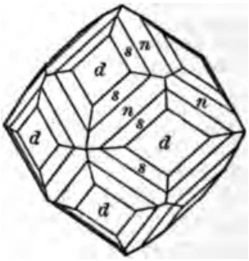
801.



802.



803.



Parting: *d* sometimes rather distinct. Fracture subconchoidal to uneven. Brittle, sometimes friable when granular massive; very tough when compact cryptocrystalline. H. = 6·5–7·5. G. = 3·15–4·3, varying with the composition. Luster vitreous to resinous. Color red, brown, yellow, white, apple-green, black; some red and green, colors often bright. Streak white. Transparent to subtranslucent. Often exhibits anomalous double refraction, especially grossularite (also topazolite, etc.); see Art. 411. Refractive index rather high, thus n_r for:

Grossularite 1·7645, Pyrope 1·7776, Almandite 1·7716.

Comp., Var.—An orthosilicate having the general formula $\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3$ or $3RO.R_2O_3.3SiO_2$. The bivalent element may be calcium, magnesium, ferrous iron or manganese; the trivalent element, aluminium, ferric iron or chromium, rarely titanium; further, silicon is also sometimes replaced by titanium.

There are three prominent groups, and various subdivisions under each, many of these blending into each other.

I. *Aluminium Garnet*, including		
A. GROSSULARITE	Calcium-Aluminium Garnet	$Ca_3Al_2(SiO_4)_3$
B. PYROPE	Magnesium-Aluminium Garnet	$Mg_3Al_2(SiO_4)_3$
C. ALMANDITE	Iron-Aluminium Garnet	$Fe_3Al_2(SiO_4)_3$
D. SPESSARTITE	Manganese-Aluminium Garnet	$Mn_3Al_2(SiO_4)_3$
II. *Iron Garnet*, including		
E. ANDRADITE	Calcium-Iron Garnet	$Ca_3Fe_2(SiO_4)_3$
(1) Ordinary. (2) Magnesian. (3) Titaniferous. (4) Yttriferous.		
III. *Chromium Garnet.*		
F. UVAROVITE	Calcium-Chromium Garnet	$Ca_3Cr_2(SiO_4)_3$

The name Garnet is from the Latin *granatus*, meaning *like a grain*, and directly from *pomegranate*, the seeds of which are small, numerous, and red, in allusion to the aspect of the crystals.

A. GROSSULARITE. Essonite or Hessonite. Cinnamon-stone. *Calcium-aluminium Garnet.* Formula $3CaO.Al_2O_3.3SiO_2$ = Silica 40·0, alumina 22·7, lime 37·3 = 100. Often containing ferrous iron replacing the calcium, and ferric iron replacing aluminium, and hence graduating toward groups C and E. G. = 3·55 to 3·66. Color (*a*) colorless to white; (*b*) pale green; (*c*) amber- and honey-yellow; (*d*) wine-yellow, brownish yellow, cinnamon-brown; (*e*) rose-red; rarely (*f*) emerald-green from the presence of chromium. Often shows optical anomalies (Art. 411).

The original *grossularite* (*wiluite* pt.) included the pale green from Siberia, and was so named from the botanical name for the gooseberry; G. = 3·42–3·72. *Cinnamon-stone*, or *essonite* (more properly *hessonite*), included a cinnamon-colored variety from Ceylon, there called *hyacinth;* but under this name the yellow and yellowish-red kinds are usually included; named from ἧσσων, *inferior*, because of less hardness than the true hyacinth which it resembles. *Succinite* is an amber-colored kind from the Ala valley, Piedmont. *Romanzovite* is brown.

Pale green, yellowish, and yellow-brown garnets are not invariably grossularite; some (including topazolite, demantoid, etc.) belong to the group of Calcium-Iron Garnet, or Andradite.

B. PYROPE. Precious garnet pt. *Magnesium-aluminium Garnet.* Formula $3MgO.Al_2O_3.3SiO_2$ = Silica 44·8, alumina 25·4, magnesia 29·8 = 100. Magnesia predominates, but calcium and iron are also present; the original pyrope also contained chromium. G. = 3·70–3·75. Color deep red to nearly black. Often perfectly transparent and then prized as a gem. The name *pyrope* is from πυρωπός, *fire-like.*

Rhodolite, of delicate shades of pale rose-red and purple, brilliant by reflected light, corresponds in composition to two parts of pyrope and one of almandite; from Macon Co., N. C.

C. ALMANDITE. Almandine. Precious garnet pt. Common garnet pt. *Iron-aluminium Garnet.* Formula $3FeO.Al_2O_3.3SiO_2$ = Silica 36·2, alumina 20·5, iron protoxide 43·3 = 100. Ferric iron replaces the aluminium to a greater or less extent. Magnesium also replaces the ferrous iron, and thus it graduates toward pyrope, cf. rhodolite above. G. = 3·9–4·2. Color fine deep red, transparent, in *precious garnet;* brownish red, translucent or subtranslucent, in *common garnet;* black. Part of common garnet belongs to *Andradite.*

The Alabandic carbuncles of Pliny were so called because cut and polished at Alabanda. Hence the name almandine or almandite, now in use.

D. SPESSARTITE. Spessartine. *Manganese-aluminium Garnet.* Formula $3MnO.Al_2O_3.3SiO_2$ = Silica 36·4, alumina 20·6, manganese protoxide 43·0 = 100. Ferrous iron replaces the manganese to a greater or less extent, and ferric iron also the aluminium. G. = 4·0–4·3. Color dark hyacinth-red, sometimes with a tinge of violet, to brownish red.

E. ANDRADITE. Common Garnet, Black Garnet, etc. *Calcium-iron Garnet.* Formula $3CaO.Fe_2O_3.3SiO_2$ = Silica 35·5, iron sesquioxide 31·5, lime 33·0 = 100. Aluminium replaces the ferric iron; ferrous iron, manganese and sometimes magnesium replace the calcium. G. = 3·8–3·9. Colors various: wine-, topaz- and greenish yellow, apple-green to emerald-green; brownish red, brownish yellow; grayish green, dark green; brown; grayish black, black.

Named *Andradite* after the Portuguese mineralogist, d'Andrada, who in 1800 described and named one of the included subvarieties, Allochroite. Chemically there are the following varieties:

1. Simple *Calcium-iron Garnet,* in which the protoxides are wholly or almost wholly lime. Includes: (*a*) *Topazolite,* having the color and transparency of topaz, and also sometimes green; crystals often showing a vicinal hexoctahedron. *Demantoid,* a grass-green to emerald-green variety with brilliant diamond-like luster, used as a gem. (*b*) *Colophonite,* a coarse granular kind, brownish yellow to dark reddish brown in color, resinous in luster, and usually with iridescent hues; named after the resin *colophony.* (*c*) *Melanite* (from μέλας, *black*), black, either dull or lustrous; but all black garnet is not here included. *Pyreneite* is grayish black melanite. (*d*) Dark green garnet, not distinguishable from some allochroite, except by chemical trials.

2. *Manganesian Calcium-iron Garnet.* (*a*) *Rothoffite.* The original *allochroite* was a manganesian iron-garnet of brown or reddish-brown color, and of fine-grained massive structure. *Rothoffite,* from Långban, is similar, yellowish brown to liver-brown. Other common kinds of manganesian iron-garnet are light and dark, dusky green and black, and often in crystals. *Polyadelphite* is a massive brownish-yellow kind, from Franklin Furnace, N. J. *Bredbergite,* from Sala, contains a large amount of magnesia. (*b*) *Aplome* (properly haplome) has its dodecahedral faces striated parallel to the shorter diagonal, whence Haüy inferred that the fundamental form was the cube; and as this form is simpler than the dodecahedron, he gave it a name derived from ἁπλόος, simple. Color of the original aplome (of unknown locality) dark brown; also found yellowish green and brownish green at Schwarzenberg in Saxony, and on the Lena in Siberia.

3. *Titaniferous.* Contains titanium and probably both TiO_2 and Ti_2O_3; formula hence $3CaO.(Fe,Ti,Al)_2O_3.3(Si,Ti)O_2$. It thus graduates toward schorlomite. Color black.

4. *Yttriferous Calcium-iron Garnet; Yttergranat.* Contains yttria in small amount; rare.

F. UVAROVITE. Ouvarovite. Uwarowit. *Calcium-chromium Garnet.* Formula $3CaO.Cr_2O_3.3SiO_2$ = Silica 35·9, chromium sesquioxide 30·6, lime 33·5 = 100. Aluminium takes the place of the chromium in part. H. = 7·5. G. = 3·41–3·52. Color emerald-green.

Pyr., etc.—Most varieties of garnet fuse easily to a light brown or black glass; F. = 3 in almandite, spessartite, grossularite, and allochroite; 3·5 in pyrope; but uvarovite, the chrome-garnet, is almost infusible, F. = 6. Allochroite and almandite fuse to a magnetic globule. Reactions with the fluxes vary with the bases. Almost all kinds react for iron; strong manganese reaction in spessartite, and less marked in other varieties; a chromium reaction in uvarovite, and in most pyrope. Some varieties are partially decomposed by acids; all except uvarovite are after ignition decomposed by hydrochloric acid, and generally with separation of gelatinous silica on evaporation. Decomposed on fusion with alkaline carbonates.

The density of garnets is largely diminished by fusion. Thus a Greenland garnet fell from 3·90 to 3·05 on fusion, and a Vilui grossularite from 3·63 to 2·95.

Diff.—Characterized by isometric crystallization, usually in isolated crystals, dodecahedrons or trapezohedrons; massive forms rare, then usually granular. Also distinguished by hardness, vitreous luster, and in the common kinds the fusibility. Vesuvianite fuses more easily, zircon and quartz are infusible; the specific gravity is higher than for tourmaline, from which it differs in form; it is much harder than sphalerite.

Distinguished in thin sections by its very high relief; lack of cleavage; isotropic character; usually shows a pale pink color; sometimes not readily told from some of the spinels.

Obs.—*Grossularite* is especially characteristic of metamorphosed impure calcareous rocks, whether altered by local igneous or general metamorphic processes; it is thus commonly found in the contact zone of intruded igneous rocks and in the crystalline schists. *Almandite* is characteristic of the mica schists and metamorphic rocks containing alumina and iron: it occurs also in some igneous rocks as the result of later dynamic and metamorphic processes; it forms with smaragdite the rock eclogite. *Pyrope* is especially characteristic of such basic igneous rocks as are formed from magmas containing much magnesia and iron with little or no alkalies, as the peridotites, dunites, etc.; also found in the serpentines formed from these rocks; then often associated with spinel, chromite, etc. *Spessartite* occurs in granitic rocks, in quartzite, in whetstone schists (Belgium); it has been noted with topaz in lithophyses in rhyolite (Colorado). The black variety of andradite, *melanite*, is common in eruptive rocks, especially with nephelite, leucite, thus in phonolites, leucitophyres, nephelinites; in such cases often titaniferous or associated with a titaniferous garnet, sometimes in zonal intergrowth; it also occurs as a product of contact metamorphism. *Demantoid* occurs in serpentine. *Uvarovite* belongs particularly with chromite in serpentine; it occurs also in granular limestone.

Garnet crystals often contain inclusions of foreign matter, but only in part due to alteration; as, vesuvianite, calcite. epidote, quartz (Fig. 472, p. 141); at times the garnet is a mere shell, or perimorph, surrounding a nucleus of another species. A black garnet from Arendal, Norway, contains both calcite and epidote; crystals from Tvedestrand are wholly calcite within, there being but a thin crust of garnet. Crystals from East Woodstock, Maine, are dodecahedrons with a thin shell of cinnamon-stone enclosing calcite; others from Raymond, Me., show successive layers of garnet and calcite. Many such cases have been noted.

804.

Garnets are often altered, thus to chlorite, serpentine; even to limonite. Crystals of pyrope are sometimes surrounded by a chloritic zone (kelyphite of Schrauf) not homogeneous, as shown in Fig. 804.

Among prominent foreign localities of garnets, besides those already mentioned, are the following—GROSSULARITE: Fine *cinnamon-stone* comes from Ceylon; on the Mussa-Alp in the Ala valley in Piedmont, with clinochlore and diopside; at Zermatt; pale yellow at Auerbach; brownish (*romanzovite*) at Kimito in Finland; honey-yellow *octahedrons* in Elba; pale greenish from the banks of the Vilui in Siberia, in serpentine with vesuvianite; also from Cziklowa and Orawitza in the Banat; with vesuvianite and wollastonite in ejected masses at Vesuvius; in white or colorless crystals in Tellemark, in Norway; also dark brown at Mudgee, New South Wales; dark honey-yellow at Guadalcazar, and clear pink or rose-red dodecahedrons at Morelos, Mexico.

PYROPE: In serpentine (from peridotite) near Meronitz and the valley of Krems, in Bohemia (used as a gem); at Zöblitz in Saxony; in the Vosges; in the diamond diggings of South Africa ("Cape rubies"). ALMANDITE: Common in granite, gneiss, eclogite, etc., in many localities in Saxony, Silesia, etc.; at Eppenreuth near Hof, Bavaria; in large dodecahedrons at Falun in Sweden; hyacinth-red or brown in the Zillerthal, Tyrol. Precious garnet comes in fine crystals from Ceylon, Pegu, British India, Brazil, and Greenland. SPESSARTITE: From Aschaffenburg in the Spessart, Bavaria; at St. Marcel, Piedmont; near Chanteloube, Haute-Vienne, etc.

ANDRADITE: The beautiful green *demantoid* or "Uralian emerald" occurs in transparent greenish rolled pebbles, also in crystals, in the gold washings of Nizhni-Tagilsk in the Ural; green crystals occur at Schwarzenberg, Saxony; brown to green at Morawitza and Dognacska; emerald-green at Dobschau; in the Ala valley, Piedmont, the yellow to greenish *topazolite*. *Allochroite*, apple-green and yellowish, occurs at Zermatt; black crystals (*melanite*), also brown, at Vesuvius on Mte. Somma; near Barèges in the Hautes-Pyrénées (*pyreneite*). *Aplome* occurs at Schwarzenberg in Saxony, in brown to black crystals. Other localities are Pfitschthal, Tyrol; Långban, Sweden; Pitkäranta, Finland; Arendal, Norway. UVAROVITE: Found at Saranovskaya near Bisersk, also in the vicinity of Kyshtymsk, Ural, in chromic iron; at Jordansmühl, Silesia; Pic Posets near Vénasque in the Pyrenees on chromite.

In N. America, in *Maine*, beautiful crystals of cinnamon-stone (with vesuvianite) occur at Parsonsfield, Phippsburg, and Rumford. In *N. Hamp.*, at Hanover, small clear crystals in gneiss; at Warren, cinnamon garnets; at Grafton. In *Vermont*, at New Fane, in chlorite slate. In *Mass*, in gneiss at Brookfield; in fine dark red or nearly black trapezohedral crystals at Russell, sometimes very large. In *Conn*, trapezohedrons, in mica slate, at Reading and Monroe; dodecahedrons at Southbury; at Haddam, crystals of spessartite. In *N. York*, brown crystals at Crown Point, Essex Co.; colophonite as a large vein at Willsboro, Essex Co.; in Middletown, Delaware Co., large brown cryst.; a cinnamon variety at Amity. In *N. Jersey*, at Franklin, black, brown, yellow, red, and green dodecahedral garnets; also near the Franklin Furnace (*polyadelphite*). In *Penn.*, in Chester Co., at Pennsbury, fine dark brown crystals; near Knauertown; at Chester, brown; in Concord, on Green's Creek, resembling pyrope; in Leiperville, red; at Mineral Hill, fine brown; at Avondale quarry, fine hessonite; uvarovite at Woods' chrome mine, Lancaster Co. In *Virginia*, beautiful transparent spessartite, used as a gem, at the mica mines at Amelia Court-House. In *N. Carolina*, fine cinnamon-stone at Bakersville; red garnets in the gold washings of Burke, McDowell, and Alexander counties; *rhodolite* in Macon Co.; also mined near Morgantown and Warlich, Burke Co., to be used as "emery," and as "garnet-paper." In *Kentucky*, fine pyrope in the peridotite of Ellis Co. In *Arkansas*, at Magnet Cove, a titaniferous melanite with schorlomite. Large dodecahedral crystals altered to chlorite occur at the Spurr Mt. iron mine, Lake Superior. In *Colorado*, at Nathrop, fine spessartite crystals in lithophyses in rhyolite; in large dodecahedral crystals at Ruby Mt., Salida, Chaffee Co., the exterior altered to chlorite. In *Arizona*, yellow-green crystals in the Gila cañon; pyrope on the Colorado river in the western part of the territory. *New Mexico*, fine pyrope on the Navajo reservation with chrysolite and a chrome-pyroxene. In *California*, green with copper ore, Hope Valley, El Dorado Co.; uvarovite, in crystals on chromite, at New Idria. Fine crystals of a rich red color and an inch or more in diameter occur in the mica schists at Fort Wrangell, mouth of the Stickeen R., in *Alaska*.

In *Canada*, at Marmora, dark red; at Grenville, a cinnamon-stone; an emerald-green chrome-garnet, at Orford, Quebec, with millerite and calcite; fine colorless to pale olive-green, or brownish crystals, at Wakefield, Ottawa Co., Quebec, with white pyroxene, honey-yellow vesuvianite, etc., also others bright green carrying chromium; dark red garnet in the townships of Villeneuve (spessartite) and Templeton.

Schorlomite. Probably analogous to garnet, $3CaO.(Fe,Ti)_2O_3.3(Si,Ti)O_2$. Schorlamit. Usually massive, black, with conchoidal fracture and vitreous luster. H. = 7–7·5. G. = 3·81–3·88. From Magnet Cove, Arkansas.

Partschinite. $(Mn,Fe)_3Al_2Si_3O_{12}$ like spessartite. In small dull crystals (monoclinic). H. = 6·5–7. G. = 4·006. Color yellowish, reddish. From the auriferous sands of Oláhpian, Transylvania.

Agricolite. Same as for eulytite, $Bi_4Si_3O_{12}$, but monoclinic. In globular or semi-globular forms. From Johanngeorgenstadt.

Chrysolite Group. R_2SiO_4. Orthorhombic.

		mm''' 110 ∧ 110	*hb'* 011 ∧ 0$\bar{1}$0	$\breve{a} : \bar{b} : \dot{c}$
Monticellite	$CaMgSiO_4$	46° 54′	59° 52′	0·4337 : 1 : 0·5758
Forsterite	Mg_2SiO_4	49° 51′	60° 43′	0·4648 : 1 : 0·5857
Chrysolite	$(Mg,Fe)_2SiO_4$	49° 57′	60° 47′	0·4656 : 1 : 0·5865
Hortonolite	$(Fe,Mg,Mn)_2SiO_4$			
Fayalite	Fe_2SiO_4	49° 15′	60° 10′	0·4584 : 1 : 0·5793
Knebelite	$(Fe,Mn)_2SiO_4$			
Tephroite	Mn_2SiO_4	49° 24′	61° 25′	0·4600 : 1 : 0·5939

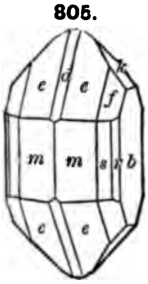
The **Chrysolite Group** includes a series of orthosilicates of magnesium, calcium, iron and manganese. They all crystallize in the orthorhombic system with but little variation in axial ratio. The prismatic angle is about 50°, and that of the unit brachydome about 60°; corresponding to the latter threefold twins are observed. The type species is chrysolite (or olivine), which contains both magnesium and iron in varying proportions and is hence intermediate between the comparatively rare magnesium and iron silicates.

In form the species of the Chrysolite Group, R_2SiO_4, are closely related in angle to Chrysoberyl, $BeAl_2O_4$; also somewhat less closely to the species of the Diaspore Group, $H_2Al_2O_4$, etc. Cf. Brögger, Zs. Kryst., 18, 377, 1890. There is also an interesting relation between the chrysolites and the humites (see p. 443)

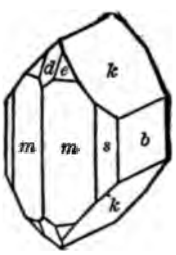
CHRYSOLITE. Olivine. Peridot.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·46575 : 1 : 0·5865.

805.



806.



mm''', 110 ∧ $1\bar{1}0$ = 49° 57'.
ss', 120 ∧ $\bar{1}20$ = 94° 4'.
dd', 101 ∧ $\bar{1}01$ = 103° 6'.
kk, 021 ∧ $0\bar{2}1$ = 99° 6'.
ee''', 111 ∧ $1\bar{1}1$ ≐ 40° 5'.
ff''' 121 ∧ $1\bar{2}1$ = 72° 13'.

Twins rare: tw. pl. *h* (011) with $c\underline{c}$ = 60° 47', penetration-twins, sometimes repeated; tw. pl. *w* (012), the vertical axes crossing at an angle of about 30°, since $c\underline{c}$ = 32° 41'. Crystals often flattened ‖ *a* or *b* (cf. Fig. 62, p. 27), less commonly elongated ‖ $\dot{c}$. Massive, compact, or granular; in embedded grains.

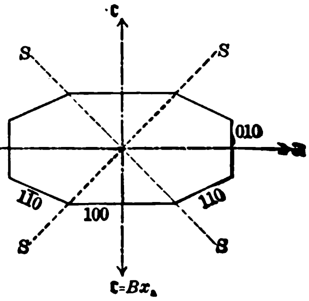
Cleavage; *b* rather distinct; *a* less so. Fracture conchoidal. Brittle. H. = 6·5–7. G. = 3·27–3·37, increasing with the amount of iron; 3·57 for hyalosiderite (30 p. c. FeO). Luster vitreous. Color green—commonly olive-green, sometimes brownish, grayish red, grayish green, becoming yellowish brown or red by oxidation of the iron. Streak usually uncolored, rarely yellowish. Transparent to translucent. Optically +. Ax. pl. ‖ *c*. Bx ⊥ *a*. Dispersion $\rho < v$, weak. $2H_{a.r}$ = 105° 58'. $\beta_y = 1·678$. Birefringence high, $\gamma - \alpha = 0·036$.

Var.—*Precious.*—Of a pale yellowish-green color, and transparent. G. = 3·441, 3 351. Occasionally seen in masses as large as "a turkey's egg," but usually much smaller. It has long been brought from the Levant for jewelry, but the exact locality is not known.

Common; Olivine.—Dark yellowish green to olive- or bottle-green. G. = 3·26-3·40. Disseminated in crystals or grains in basic igneous rocks, basalt and basaltic lavas, etc. *Hyalosiderite* is a highly ferruginous variety.

Comp.—$(Mg,Fe)_2SiO_4$ or $2(Mg,Fe)O.SiO_2$. The ratio of Mg : Fe varies widely, from 16 : 1, 12 : 1, etc., to 2 : 1 in hyalosiderite, and hence passing from fosterite on the one side to fayalite on the other. No sharp line can be drawn on either side. Titanium dioxide is sometimes present replacing silica; also tin and nickel in minute quantities.

807.

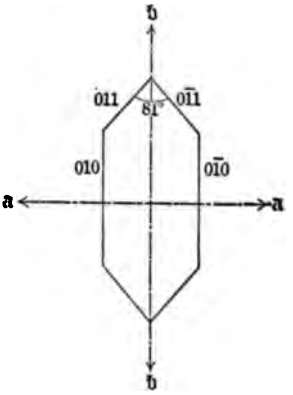


Pyr., etc.—B.B. whitens, but is infusible in most cases; hyalosiderite and other varieties rich in iron fuse to a black magnetic globule; some kinds turn red upon heating. With the fluxes gives reactions for iron. Some varieties give reactions for titanium and manganese. Decomposed by hydrochloric and sulphuric acids with separation of gelatinous silica.

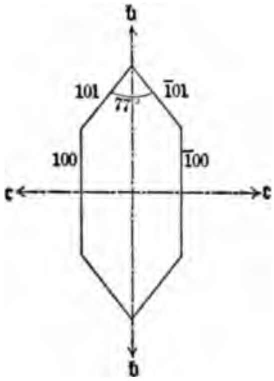
Diff—Characterized by its infusibility, the yellow-green color, granular form and cleavage (quartz has none).

Recognized in thin sections by its high relief; lack of color; its few but marked rough cleavage-cracks; high interference-colors, which are usually the brilliant and pronounced tones of the second order; parallel extinction; biaxial character; characteristic outlines (usually with acute terminations) when in distinct crystals (Figs. 807–809), its frequent association with iron ore and augite, and its very common alteration, in a greater or lesser degree, to serpentine, the first stages being marked by the separation of iron-ore grains along the lines of fracture (Fig. 810).

808



809.



810.

Obs.—Chrysolite (olivine) has two distinct methods of occurrence: (*a*) in igneous rocks, as basalt, formed by the crystallization of magmas low in silica and rich in magnesia; from an accessory component in such rocks the olivine may increase in amount until it is the main rock constituent as in the dunites; also (*b*) as the product of metamorphism of certain sedimentary rocks containing magnesia and silica, as in impure dolomites. In the dunites and peridotites of igneous origin the chrysolite is commonly associated with chromite, spinel, pyrope, etc., which are valuable indications also of the origin of serpentines derived from olivine. In the metamorphic rocks the above are wanting, and carbonates, as dolomite, breunnerite, magnesite, etc., are the common associations; chrysolitic rocks of this latter kind may also occur altered to serpentine.

Chrysolite also occurs in grains, rarely crystals, embedded in some meteoric irons. Also present in meteoric stones, frequently in spherical forms, or chondrules, sometimes made up of a multitude of grains with like (or unlike) optical orientation enclosing glass between (Fig. 811).

Among the more prominent localities are: Vesuvius in lava and on Monte Somma in ejected masses, with augite, mica, etc. Observed in the so-called sanidine bombs at the Laacher See; at Forstberg near Mayen in the Eifel and forming the mass of "olivine bombs" in the Dreiser Weiher near Daun in the same region; at Sasbach in the Kaiserstuhl, Baden (*hyalosiderite*). In Sweden, with ore-deposits, as at Långban, Pajsberg, Persberg, etc. In serpentine at Snarum, Norway, in large crystals, themselves altered to the same mineral. Common in the volcanic rocks of Sicily, the Sandwich Islands, the Azores, etc.

811.

Chrysolite chondrule from the Knyahinya meteorite (×10 diam.).

In the U. S., in Thetford and Norwich, Vermont, in boulders of coarsely cryst. basalt, the crystals or masses several inches through. In olivine-gabbro of Waterville, in the White Mts., N. H.; at Webster, in Jackson Co., N. C., with serpentine and chromite; with chromite in Loudon Co., Va.; in Lancaster Co., Pa. In small clear olive-green grains with garnet at some points in Arizona and New Mexico. In basalt in Canada, near Montreal, at Rougemont and Mounts Royal and Montarville, and in eruptive rocks at other points.

Alteration of chrysolite often takes place through the oxidation of the iron; the mineral becomes brownish or reddish brown and iridescent. The process may end in leaving the cavity of the crystal filled with limonite or red oxide of iron. A very common kind of alteration is to the hydrous magnesium silicate, serpentine, with the partial removal of the iron or its separation in the form of grains of magnetite, also as iron sesquioxide; this change has often taken place on a large scale. See further under serpentine, p. 477.

Chrysolite is named from χρυσός, *gold*, and λίθος. The hyalosiderite, from ὕαλος, *glass*, and σίδηρος, *iron*. The *chrysolithus* of Pliny was probably our topaz; and his *topaz* our *chrysolite*.

Iddingsite. From the rock carmeloite of Carmelo Bay, California; a silicate resembling an altered chrysolite, exact composition undetermined. Orthorhombic, foliated and cleavable. G. = 2·839. Color brown.

The axial ratios of the other members of the Chrysolite Group are given in the table on p. 419. The species are briefly characterized as follows:

Monticellite. $CaMgSiO_4$. Occurs in colorless to gray crystals on Mte. Somma; in masses (*batrachite*) on Mt. Monzoni, Tyrol; in crystals or grains in limestone at Magnet Cove, Arkansas. G. = 3·03–3·25.

Forsterite. Mg_2SiO_4. Occurs in white crystals at Vesuvius; in greenish or yellowish embedded grains at Bolton, Mass. (*boltonite*). G. = 3·21–3·33.

Hortonolite. $(Fe,Mg,Mn)_2SiO_4$. In rough dark-colored crystals or masses. Occurs at the iron mine of Monroe, Orange Co., N. Y. G. = 3·91.

Fayalite. Fe_2SiO_4. From the Mourne Mts., Ireland; the Azores; the Yellowstone Park; Rockport, Mass., etc. Crystals and massive, brown to black on exposure. G. = 4·1.

Knebelite. $(Fe,Mn)_2SiO_4$. From Dannemora, and elsewhere in Sweden. G. = 4·1.

Tephroite. Mn_2SiO_4; also with zinc, in the variety *roepperite*. From Sterling Hill and Franklin Furnace, N. J.; also from Sweden. Color flesh-red to ash-gray. G. = 4·1.

Phenacite Group. R_2SiO_4. Tri-rhombohedral.

		rr'	$\dot{c}$
Willemite	Zn_2SiO_4	64° 30′	0·6775
Troostite	$(Zn,Mn)_2SiO_4$		
Phenacite	Be_2SiO_4	63° 24′	0·6611

The Phenacite Group includes the above orthosilicates of zinc (manganese) and beryllium. Both belong to the tri-rhombohedral group of the trigonal division of the hexagonal system, and have nearly the same rhombohedral angle. The rare species trimerite, $MnSiO_4.BeSiO_4$, which is pseudo-hexagonal (triclinic) is probably to be regarded as connecting this group with the preceding Chrysolite Group.

The following rare species are related:

			rr'	$\dot{c}$
Dioptase	H_2CuSiO_4	Tri-rhombohedral	54° 5′	0·5342
Friedelite	$H_7(MnCl)Mn_4(SiO_4)_4$		56° 17′	0·5624
Pyrosmalite	$H_7((Fe,Mn)Cl)(Fe,Mn)_4(SiO_4)_4$		53° 49′	0·5308

These species are very near to each other in form, as shown in the above axial ratios: they further approximate to the species of the Phenacite Group proper. They are also closely related among themselves in composition, since they are all acid orthosilicates, and have the general formula $H_2RSiO_4 = H_8R_4(SiO_4)_4$, where (*e.g.* for Friedelite) in the latter form the place of one hydrogen atom is taken by the univalent radical (MnCl).

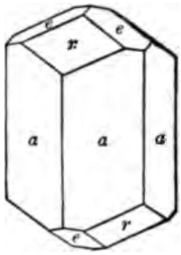
WILLEMITE.

Tri-rhombohedral. Axis $\dot{c} = 0·6775$; $rr' = 64° 30'$; $ee' = 36° 47'$.

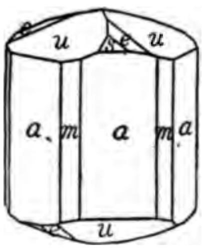
In hexagonal prisms, sometimes long and slender, again short and stout; rarely showing subordinate faces distributed according to the phenacite type. Also massive and in disseminated grains; fibrous.

Cleavage: *c* easy, Moresnet; difficult, N. J.; *a* easy, N. J. Fracture conchoidal to uneven. Brittle. H. = 5·5. G. = 3·89–4·18. Luster vitreoresinous, rather weak. Color white or greenish yellow, when purest; apple-green, flesh-red, grayish white, yellowish brown; often dark brown when impure. Streak uncolored. Transparent to opaque. Optically +. Birefringence high.

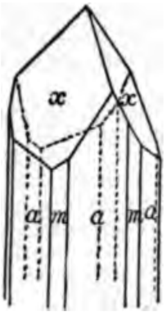
812.



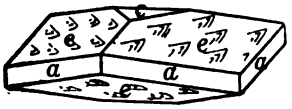
813.



814.



815.



Colorado.

Figs. 812–814, New Jersey. *e* $(0\bar{1}12)$, *s* $(11\bar{2}3)$, *u* $(2\bar{1}\bar{1}3)$, *x* $(3\bar{1}\bar{2}1)$.

Comp.—Zinc orthosilicate, Zn_2SiO_4 or $2ZnO.SiO_2$ = Silica 27·0, zinc oxide 73·0 = 100. Manganese often replaces a considerable part of the zinc (in *troostite*), and iron is also present in small amount.

Pyr., etc.—B.B. in the forceps glows and fuses with difficulty to a white enamel; the varieties from New Jersey fuse from 3·5 to 4. The powdered mineral on charcoal in R.F. gives a coating, yellow while hot and white on cooling, which, moistened with solution of cobalt, and treated in O.F., is colored bright green. With soda the coating is more readily obtained. Decomposed by hydrochloric acid with separation of gelatinous silica.

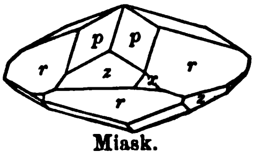
Obs.—From Altenberg near Moresnet; at Stolberg, near Aix-la-Chapelle. In New Jersey at Mine Hill, Franklin Furnace, and at Sterling Hill, two miles distant. Occurs with zincite and franklinite, varying in color from white to pale honey-yellow and light green to dark ash-gray and flesh-red; sometimes in large reddish crystals (*troostite*). Rare at the Merritt mine, Socorro Co., New Mexico; also at the Sedalia mine, Salida, Colo. Named by Lévy after William I., King of the Netherlands.

PHENACITE.

Tri-rhombohedral. Axis $\dot{c}$ = 0·6611; $rr' = 63° 24'$.

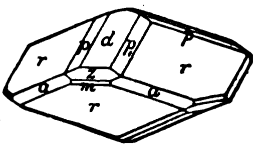
Crystals commonly rhombohedral in habit, often lenticular in form, the prisms wanting; also prismatic, sometimes terminated by the rhombohedron of the third series, *x* (see further, pp. 80–82).

816.



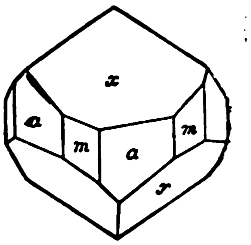
Miask.

817.



Florissant. Colo.

818.



Mt. Antero, Colo , Pfd.

Cleavage: *a* distinct; *r* imperfect. Fracture conchoidal. Brittle. H. = 7·5–8. G. = 2·97–3·00. Luster vitreous. Colorless; also bright wine-yellow, pale rose-red; brown. Transparent to subtranslucent. Optically +. $\omega_y = 1·6540$; $\epsilon_y = 1·6697$, Framont.

Comp.—Beryllium orthosilicate, Be_2SiO_4 or $2BeO.SiO_2$ = Silica 54·45, glucina 45·55 = 100.

Pyr., etc.—Alone remains unaltered; with borax fuses with extreme slowness, unless

pulverized, to a transparent glass. With soda affords a white enamel; with more, intumesces and becomes infusible. Dull blue with cobalt solution.

Obs.—Occurs at the emerald and chrysoberyl mine of Takovaya, 85 versts E. of Ekaterinburg; also in the Ilmen Mts., near Miask; near Framont in the Vosges Mts.; at the Cerro del Mercado, Durango, Mexico.

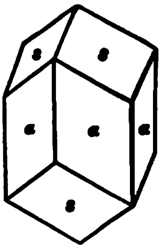
In Colorado, on amazon-stone, at Topaz Butte, near Florissant, 16 miles from Pike's Peak; also on quartz and beryl at Mt. Antero, Chaffee county. Named from *φέναξ*, *a deceiver*, in allusion to its having been mistaken for quartz.

Trimerite. $(Mn,Ca)_2SiO_4.Be_2SiO_4$. In thick tabular prismatic crystals, pseudo-hexagonal (triclinic) in form and angle. H. = 6–7. G. = 3·474. Color salmon-pink to nearly colorless in small crystals. From the Harstig mine, Wermland, Sweden.

Dioptase. H_2CuSiO_4 or $H_2O.CuO.SiO_2$. Commonly in prismatic crystals ($ss' = 84° 33\frac{1}{2}'$). Also in crystalline aggregates; massive. Cleavage: *r* perfect. Fracture conchoidal to uneven. H. = 5. G. = 3·28–3·35. Luster vitreous. Color emerald-green.

Occurs in druses of well-defined crystals on quartz, occupying seams in a compact limestone west of the hill of Altyn-Tübe in the Kirghese Steppes; in the gold washings at several points in Siberia; at Rezbánya, Hungary. From Copiapo, Chili, on quartz with other copper ores. In fine crystals at the Mine Mindouli, two leagues east of Comba, in the French Congo State. Also at the copper mines of Clifton, Graham Co., Arizona.

819.



Friedelite. $H_7(MnCl)Mn_4Si_4O_{16}$. Crystals commonly tabular ∥ *c*; also massive, cleavable to closely compact. H. = 4–5. G. = 3·07. Color rose-red. From the manganese mine of Adervielle, vallée du Louron, Hautes Pyrénées.

Pyrosmalite. $H_7((Fe,Mn)Cl)(Fe,Mn)_4Si_4O_{16}$. Crystals thick hexagonal prisms or tabular; also massive, foliated. H. = 4–4·5. G. = 3·06–3·19. Color blackish green to pale liver-brown or gray.. From the iron mines of Nordmark in Wermland; Dannemora, Sweden.

Scapolite Group. Tetragonal-pyramidal.

Meionite	$\dot{c} = 0·4393$	**Mizzonite**, Dipyre	$\dot{c} = 0·4424$
Wernerite	$\dot{c} = 0·4384$	**Marialite**	$\dot{c} = 0·4417$

Sarcolite $\frac{1}{2}\dot{c} = 0·4437$

The species of the Scapolite Group crystallize in the pyramidal group of the tetragonal system with nearly the same axial ratio. They are white or grayish white in color, except when impure, and then rarely of dark color. Hardness = 5–6·5; G. = 2·5–2·8. In composition they are silicates of aluminium with calcium and sodium in varying amounts; chlorine is also often present, sometimes only in traces. Iron, magnesia, potash are not present unless by reason of inclusions or of alteration, which last cause also explains the carbon dioxide often found in analysis.

The Scapolites are analogous to the Feldspars in that they form a series with a gradual variation in composition, the amount of silica increasing with the increase of the alkali, soda, being 40 p. c. in meionite and 64 p. c. in marialite. A corresponding increase is observed also in the amount of chlorine present. Furthermore there is also a gradual change in specific gravity, in the strength of the double refraction, and in resistance to acids, from the easily decomposed meionite, with G. = 2·72, to marialite, which is only slightly attacked and has G. = 2·63. Tschermak has shown that the variation in composition may be explained by the assumption of two fundamental end compounds, viz.:

Meionite	$Ca_4Al_6Si_6O_{25}$	Me
Marialite	$Na_4Al_3Si_9O_{24}Cl$	Ma

By the isomorphous combination of these compounds the composition of the species mentioned above may be explained; no sharp line can, however, be drawn between them.

Optically the series is characterized by the decrease in the strength of the double refraction in passing from meionite to marialite. Thus (Lacroix) for meionite $\omega - \epsilon = 0.036$; for typical wernerite 0·03–0·02; for dipyre 0·015.

The tetragonal species melilite and gehlenite are near the Scapolites in angle. The more common vesuvianite is also related.

MEIONITE.

Tetragonal. Axis $\dot{c} = 0{\cdot}43925$. In prismatic crystals (Fig. 179, p. 60), either clear and glassy or milky white; also in crystalline grains and massive. Cleavage: *a* rather perfect, *m* somewhat less so. Fracture conchoidal. Brittle. H. = 5·5–6 G. = 2·70–2·74. Luster vitreous. Colorless to white. Transparent to translucent; often cracked within. Optically —. Double refraction weak. Indices, Dx.: $\omega_y = 1{\cdot}594$; $\epsilon_y = 1{\cdot}558$.

Comp.—$Ca_4Al_6Si_6O_{25}$ or $4CaO.3Al_2O_3.6SiO_2$ = Silica 40·5, alumina 34·4, lime 25·1 = 100.

The varieties included here range from nearly pure meionite to those consisting of meionite and marialite in the ratio of 3 : 1, *i.e.*, Me : Ma = 3 : 1. No sharp line can be drawn between meionite and the following species.

Obs.—Occurs in small crystals in cavities, usually in limestone blocks, on Monte Somma. Also in ejected masses at the Laacher See.

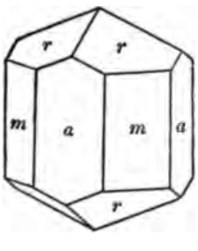
WERNERITE. Common Scapolite.

Tetragonal-pyramidal. Axis $\dot{c} = 0{\cdot}4384$.

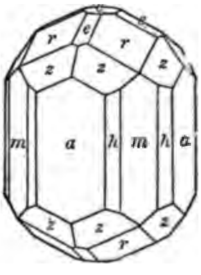
Crystals prismatic, usually coarse, with uneven faces and often large. The symmetry of the pyramidal group sometimes shown in the development of the faces *z* (311) and z_1(131). Also massive, granular, or with a faint fibrous appearance; sometimes columnar.

ee', $101 \wedge 011 = 32° 59'$.
rr', $111 \wedge \bar{1}11 = 43° 45'$.
mr, $110 \wedge 111 = 58° 12'$.
zz,''', $311 \wedge 3\bar{1}1 = 29° 43'$.

820.



821.



Cleavage: *a* and *m* rather distinct, but interrupted. Fracture subconchoidal. Brittle. H. = 5 – 6. G. = 2·66–2·73. Luster vitreous to pearly externally, inclining to resinous; cleavage and cross-fracture surface vitreous. Color white, gray, bluish, greenish, and reddish, usually light; streak uncolored. Transparent to faintly subtranslucent. Optically —. Birefringence weak. Indices: $\omega_r = 1{\cdot}566$, $\epsilon_r = 1{\cdot}545$ Arendal.

Comp., Var.—Intermediate between meionite and marialite and corresponding to a molecular combination of these in a ratio 3 : 1 to 1 : 2. The silica varies from 46 to 54 p. c., and as its amount increases the soda and chlorine also increase. Scapolites with silica from 54 p. c. to 60 p. c. are classed with mizzonite; they correspond to Me : Ma from 1 : 2 to 1 : 3 and upwards.

The percentage composition for a common compound is as follows:

Me : Ma 3 : 1 SiO_2 46·10 Al_2O_3 30·48 CaO 19·10 Na_2O 3·54 Cl 1·01 = 100·23

Pyr., etc.—B.B. fuses easily with intumescence to a white blebby glass. Imperfectly decomposed by hydrochloric acid.

Diff.—Characterized by its square form and prismatic cleavage (90°); resembles feldspar when massive, but has a characteristic fibrous appearance on the cleavage surface; it is also more fusible, and has a higher specific gravity; also distinguished by fusibility with intumescence from pyroxene (wh. see, p. 387).

Recognized in thin sections by its low refraction; lack of color; rather high interference-colors reaching the yellows and reds of the first order, sections showing which extinguish parallel to the cleavage; by the distinct negative axial cross of basal sections which show the cleavage-cracks crossing at right angles.

Obs.—Occurs in metamorphic rocks, and most abundantly in granular limestone near its junction with the associated granitic or allied rocks; sometimes in beds of magnetite accompanying limestone. It is often associated with a light-colored pyroxene, amphibole, garnet, and also with apatite, titanite, zircon; amphibole is a less common associate than pyroxene, but in some cases has resulted from the alteration of pyroxene. Scapolite has been shown also to be frequently a component of basic igneous rocks, especially those rich in plagioclases containing much lime; it is regarded as a secondary product through a certain kind of alteration.

Prominent localities are at Pargas, Finland, where it occurs in limestone; Arendal in Norway, and Malsjö in Wermland, where it occurs with magnetite in limestone. *Passauite* is from Obernzell, near Passau, in Bavaria. The pale blue or gray scapolite from L. Baikal, Siberia, is called *glaucolite*. In the U. S., occurs in *Vermont*, at Marlborough, massive. In *Mass.*, at Bolton; at Chelmsford. In *N. York*, in Orange Co., Essex Co., Lewis Co.; Grasse Lake, Jefferson Co.; at Gouverneur, in limestone. In *N. Jersey*, at Franklin and Newton. In *Penn.*, at the Elizabeth mine, French Creek, Chester Co.

In *Canada*, at G. Calumet Id., massive; at Grenville; Templeton; Wakefield, Ottawa Co. Scapolite rocks occur at several points.

Mizzonite. Dipyre. Here are included scapolites with 54 to 57 p. c. SiO_2, corresponding to a molecular combination from Me : Ma = 1 : 2 to Me : Ma = 1 : 3. *Mizzonite* occurs in clear crystals in ejected masses on Mte. Somma.

Dipyre occurs in elongated square prisms, often slender, sometimes large and coarse, in limestone and crystalline schists, chiefly from the Pyrenees; also in diorite at Bamle, Norway; Saint-Nazaire, France; Algeria. *Couseranite* from the Pyrenees is a more or less altered form of dipyre.

Marialite. Theoretically $Na_4Al_3Si_9O_{24}Cl$, see p. 425. The actual mineral corresponds to Me : Ma = 1 : 4. It occurs in a volcanic rock called piperno, at Pianura, near Naples.

Sarcolite. $(Ca,Na_2)_3Al_2(SiO_4)_3$. In small tetragonal crystals. H. = 6. G. = 2·545–2·932. Color flesh-red. From Monte Somma.

MELILITE.

Tetragonal. Axis $\dot{c}$ = 0·4548. Usually in short square prisms (*a*) or octagonal prisms (*a*, *m*), also in tetragonal tables.

Cleavage: *c* distinct; *a* indistinct. Fracture conchoidal to uneven. Brittle. H. = 5. G. = 2·9–3·10. Luster vitreous, inclining to resinous. Color white, pale yellow, greenish, reddish, brown. Pleochroism distinct in yellow varieties. Sometimes exhibits optical anomalies. Optically —. Birefringence low. Indices:

Humboldtilite ω_r = 1·6312 ω_y = 1·6339 ϵ_r = 1·6262 ϵ_y = 1·6291 Henniger

Comp.—Perhaps $\overset{II}{R}_{12}\overset{III}{R}_4Si_9O_{36}$ or $Na_2(Ca,Mg)_{11}(Al,Fe)_4(SiO_4)_9$ for melilite. If Ca : Mg = 8 : 3, and Al : Fe = 1 : 1, the percentage composition is: Silica 37·7, alumina 7·1, iron sesquioxide 11·2, lime 31·3, magnesia 8·4, soda 4·3 = 100. Potassium is also present.

Pyr., etc.—B.B. fuses at 3 to a yellowish or greenish glass. With the fluxes reacts for iron. Decomposed by hydrochloric acid with gelatinization.

Diff.—Distinguished in thin sections by its moderate refraction; very low interference-colors, showing often the "*ultra blue*" (Capo di Bove); parallel extinction; negative character; usual development in tables parallel to the base and very common "peg structure" due to parallel rod-like inclusions penetrating the crystal from the basal planes inward: this, however, is not always easily seen.

Obs.—Melilite is a component of certain igneous rocks formed from magmas very low in silica, rather deficient in alkalies, and containing considerable lime and alumina. In such cases melilite appears to crystallize in the place of the more acid plagioclase.

Melilite of yellow and brownish colors is found at Capo di Bove, near Rome, in leucitophyre with nephelite, augite, hornblende: at Vesuvius in dull yellow crystals (*somervillite*); not uncommon in certain basic eruptive rocks, as the *melilite-basalts* of Hochbohl near Owen in Württemberg, of the Schwabian Alb, of Görlitz, the Erzgebirge; also in the nephelite basalts of the Hegau, of Oahu, Sandwich Islands, etc.; perovskite is a common associate. Common in furnace slags. Melilite is named from μέλι, *honey*, in allusion to the color.

Humboldtilite occurs in cavernous blocks on Monte Somma with greenish mica, also apatite, augite; the crystals are often rather large, and covered with a calcareous coating; less common in transparent lustrous crystals with nephelite, sarcolite, etc., in an augitic rock. *Zurlite* is impure humboldtilite.

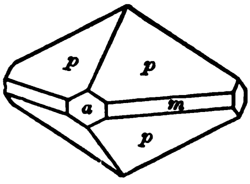
Gehlenite. $Ca_3Al_2Si_2O_{10}$. Crystals usually short square prisms. Axis $\dot{c} = 0{\cdot}4001$. G. = 2·9–3·07. Different shades of grayish green to liver-brown. From Mount Monzoni, in the Fassathal, in Tyrol.

VESUVIANITE. Idocrase.

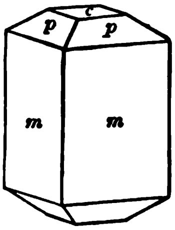
Tetragonal. Axis $\dot{c} = 0{\cdot}5372$.

ce, 001 ∧ 101 = 28° 15′.
cp, 001 ∧ 111 = 37° 13½′.
ct, 001 ∧ 331 = 66° 18′.
pp', 111 ∧ 111 = 50° 39′.
ss^{vii}, 311 ∧ $3\bar{1}1$ = 31° 38′.

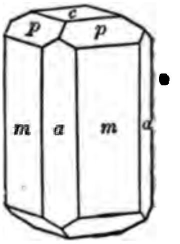
822.



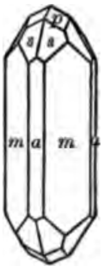
823.



824.

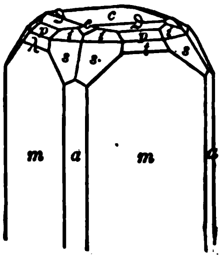


825.



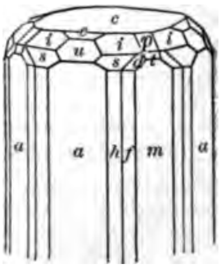
Ala.

826.



Zermatt.

827.



Sandford, Me.

Often in crystals, prismatic or pyramidal. Also massive; columnar, straight and divergent, or irregular; granular massive; cryptocrystalline.

Cleavage: *m* not very distinct; *a* and *c* still less so. Fracture subconchoidal to uneven. Brittle. H. = 6·5. G. = 3·35–3·45. Luster vitreous; often inclining to resinous. Color brown to green, and the latter frequently bright and clear; occasionally sulphur-yellow, and also pale blue. Streak white. Subtransparent to faintly subtranslucent. Dichroism not usually strong. Optically −; also + rarely. Birefringence very low. Sometimes abnormally biaxial. Indices: $\omega_y = 1·7235$, $\epsilon_y = 1·7226$ Ala, Osann.

Comp.—A basic calcium-aluminium silicate, but of uncertain formula; perhaps $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$. Ferric iron replaces part of the aluminium and magnesium the calcium. Fluorine and titanium may be present. The following are typical analyses (Jannasch):

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	Li_2O	H_2O	F.	
1. Vesuvius,	36·98	—	16·70	2·99	2·01	0·57	35·67	2·62	0·43	0·08	1·32	1·08	= 100·45
2. Vilui,	36·17	1·30	12·23	2·18	1·49	0·15	35·81	6·05	0·45	—	0·72	0·22	B_2O_3 2·81 = 99·58

Pyr., etc.—B.B. fuses at 3 with intumescence to a greenish or brownish glass. Magnus states that the density after fusion is 2·93–2·945. With the fluxes gives reactions for iron, and some varieties a strong manganese reaction. *Cyprine*, a blue variety, gives a reaction for copper with salt of phosphorus. Partially decomposed by hydrochloric acid, and completely when the mineral has been previously ignited.

Diff.—Characterized by its tetragonal form and easy fusibility. Resembles some brown varieties of garnet, tourmaline, and epidote.

Recognized in thin sections by its high refraction producing a very strong relief and its extremely low birefringence;* also in general by its color, pleochroism, and uniaxial negative character; the latter, on account of the low birefringence, being difficult to determine. The low birefringence, however, aids in distinguishing it from epidote, with which at times it may be confounded.

Obs.—Vesuvianite was first found among the ancient ejections of Vesuvius and the dolomitic blocks of Monte Somma, whence its name. It commonly occurs as a contact mineral from the alteration of impure limestones, then usually associated with lime garnet (grossularite), phlogopite, diopside, wollastonite; also epidote; also in serpentine, chlorite schist, gneiss and related rocks.

Prominent localities are Vesuvius; the Albani Mts.; the Mussa Alp in the Ala valley, in Piedmont; Mt. Monzoni in the Fassathal; at Orawitza and Dognaczka; Haslau near Eger in Bohemia (*egeran*); near Jordansmühl, Silesia; on the Vilui river, near L. Baikal (sometimes called *wiluite* or viluite, like the grossular garnet from the same region); at Arendal, "*colophonite*"; at Egg, near Christiansand.

In N. America, in *Maine* at Phippsburg and Rumford; at Sandford. In *N. Hampshire*, at Warren with cinnamon-stone. In *N. York*, ¼ m. S. of Amity. In *New Jersey*, at Newton. In *California* near San Carlos in Inyo Co. In *Canada*, at Calumet Falls, Litchfield, Pontiac Co.; at Grenville in calcite; at Templeton, Ottawa Co., Quebec.

Zircon Group. $\overset{iv}{R}SiO_4$. Tetragonal.

Zircon	$ZrSiO_4$	$\dot{c} = 0·6404$
Thorite	$ThSiO_4$	$\dot{c} = 0·6402$

This group includes the orthosilicates of zirconium and thorium, both alike in tetragonal crystallization, axial ratio and crystalline habit.

These species are sometimes regarded as oxides and then included in the RUTILE GROUP (p. 343), to which they approximate closely in form. A similar form belongs also to the tantalate, Tapiolite, and to the phosphate, Xenotime; further, compound groups consisting of crystals of Xenotime and Zircon in parallel position are not uncommon (Fig. 431, p. 181).

---

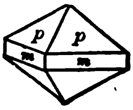
* Frequently minerals, which, like vesuvianite, mellilite and zoisite, are doubly refracting but of extremely low birefringence (and possibly, where they are positive for one color but negative for another), do not show a gray color between crossed nicols but a curious blue, at times an intense Berlin blue, which is quite distinct from the other blues of the color scale and is known as the "*ultra blue.*"

ZIRCON.

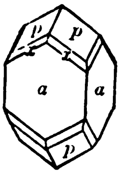
Tetragonal. Axis $\dot{c} = 0{\cdot}64037$.

ee', $101 \wedge 011 = 44° 50'$. mp, $110 \wedge 111 = 47° 50'$.
ee'', $101 \wedge \bar{1}01 = 65° 16'$. mu, $110 \wedge 331 = 20° 12\frac{1}{2}'$.
pp', $111 \wedge \bar{1}11 = 56° 40\frac{1}{2}'$. xx^{vii}, $311 \wedge 3\bar{1}1 = 32° 57'$.
uu', $331 \wedge \bar{3}31 = 83° 9'$. ax, $100 \wedge 311 = 31° 43'$.

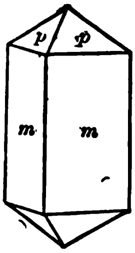
828.



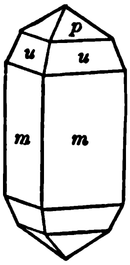
829.



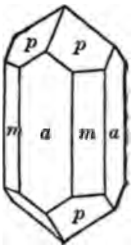
830.



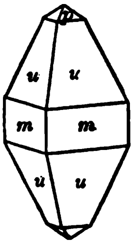
831.



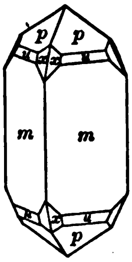
832.



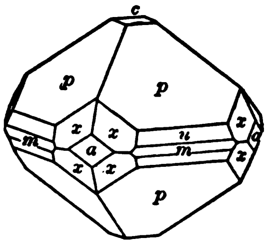
833.



834.



835.



Colorado.

Twins: tw. pl. *e* (101), geniculated twins like rutile (Fig. 374, p. 124). Commonly in square prisms, sometimes pyramidal. Also in irregular forms and grains.

Cleavage: *m* imperfect; *p* (111) less distinct. Fracture conchoidal. Brittle. H. = 7·5. G. = 4·68–4·70 most common, but varying widely to 4·2 and 4·86. Luster adamantine. Colorless, pale yellowish, grayish, yellowish green, brownish yellow, reddish brown. Streak uncolored. Transparent to subtranslucent and opaque. Optically +. Birefringence high. $\omega_y = 1{\cdot}9239$, $\epsilon_y = 1{\cdot}9682$, Ceylon. Sometimes abnormally biaxial.

Hyacinth is the orange, reddish and brownish transparent kind used for gems. *Jargon* is a name given to the colorless or smoky zircons of Ceylon, in allusion to the fact that while resembling the diamond in luster, they are comparatively worthless; thence came the name *zircon*.

Comp.—$ZrSiO_4$ or $ZrO.SiO_4$ = Silica 32·8, zirconia 67·2 = 100. A little iron (Fe_2O_3) is usually present.

Pyr., etc.—Infusible; the colorless varieties are unaltered, the red become colorless, while dark-colored varieties are made white; some varieties glow and increase in density by ignition. Not perceptibly acted upon by salt of phosphorus. In powder decomposed when fused with soda on the platinum wire, and if the product is dissolved in dilute hydrochloric acid it gives the orange color characteristic of zirconia when tested with turmeric paper. Not acted upon by acids except in fine powder with concentrated sulphuric acid. Decomposed by fusion with alkaline carbonates and bisulphates.

Diff.—Characterized by the prevailing square pyramid or square prism; also by its adamantine luster, hardness, high specific gravity, and infusibility; the diamond is optically isotropic.

Recognized in thin sections by its very high relief; very high interference-colors, which approach white of the higher order except in very thin sections; positive uniaxial character. It is distinguished from cassiterite and rutile only by its lack of color, and from the latter also in many cases by method of occurrence.

Obs.—A common constituent of igneous rocks, especially those of the more acid feldspathic groups and particularly the kinds derived from magmas containing much soda. Is generally present in minute crystals, but in pegmatitic facies often in large and well-formed crystals. Occurs more rarely elsewhere, as in granular limestone, chloritic and other schists; gneiss; sometimes in iron-ore beds. Crystals are common in most auriferous sands. Sometimes found in volcanic rocks, probably in part as inclusions derived from older rocks.

Zircon in distinct crystals is so common in the pegmatitic forms of the nephelite-syenite and augite-syenite of southern Norway (with ægirite, etc.) that this rock there and elsewhere has sometimes been called a "zircon-syenite."

Found in alluvial sands in Ceylon; in the gold regions of the Ural, at Laurvik, Norway; at Arendal, in the iron mines; at Fredriksvärn, and in veins in the augite-syenite of the Langesund fiord; Pfitschthal, Tyrol; in lava at Niedermendig in the Eifel, red crystals; etc.

In N. America, in *Maine*, at Litchfield; In *N. York*, in Moriah, Essex Co., cinnamon-red; near the outlet of Two Ponds, Orange Co., with scapolite, pyroxene and titanite; at Warwick, chocolate-brown, near Amity; in St. Lawrence Co., in the town of Hammond; at Rossie. Fine, Pitcairn. In *Penn.*, near Reading. In *N. Car.*, abundant in the gold sands of Burke, McDowell, Polk, Rutherford, Henderson, and other counties. In *Colorado*, with astrophyllite, etc., in the Pike's Peak region in El Paso Co.; at Cheyenne Mt. In *California*, in auriferous gravels.

In *Canada*, at Grenville, Argenteuil Co.; in Templeton and adjoining townships in Ottawa Co., Quebec; in Renfrew Co., sometimes very large; in North Burgess, Lanark Co.

Malacon is an altered zircon. *Cyrtolite* is related but contains uranium, yttrium and other rare elements.

$ThSiO_4$-formula

Thorite. Thorium silicate, ThO_2, like zircon in form; usually hydrated, black in color, and then with G. = 4·5–5; also orange-yellow and with G. = 5·19–5·40 (*orangite*). From the Brevik region, Norway; also near Arendal. And in Madagascar.

Auerlite. Like zircon in form; supposed to be a silico-phosphate of thorium. Henderson Co., N. C.

also in Ceylon.

Danburite-Topaz Group. Orthorhombic. $\overset{\text{II}}{R}\overset{\text{III}}{R}_2(SiO_4)_2$ or $(\overset{\text{III}}{R}O)\overset{\text{III}}{R}SiO_4$.

Danburite	$CaB_2(SiO_4)_2$	$\breve{a} : \bar{b} : \dot{c} = 0·5444 : 1 : 0·4807$
Topaz	$[Al(F,OH)_2]AlSiO_4$	$\breve{a} : \bar{b} : \dot{c} = 0·5285 : 1 : 0·4770$
Andalusite	$(AlO)AlSiO_4$	$\frac{1}{2}\bar{b} : \breve{a} : \frac{2}{3}\dot{c} = 0·5070 : 1 : 0·4749$
		or $\breve{a} : \bar{b} : \dot{c} = 0·9861 : 1 : 0·7025$

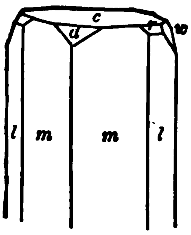
Sillimanite	Al_2SiO_5	Orthorhombic	$\breve{a} : \bar{b} = 0·970 : 1$
Cyanite	Al_2SiO_5	Triclinic	

$\breve{a} : \bar{b} : \dot{c} = 0·8994 : 1 : 0·7090$; $\alpha = 90° 5\frac{1}{2}'$, $\beta = 101° 2'$, $\gamma = 105° 44\frac{1}{2}'$.

DANBURITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}5444 : 1 : 0{\cdot}4807$.

836.



mm''', $110 \wedge \bar{1}10 = 57° 8'$. dd', $101 \wedge \bar{1}01 = 82° 53'$.
ll', $120 \wedge \bar{1}20 = 85° 8'$. ww', $041 \wedge 0\bar{4}1 = 125° 8'$.

Habit prismatic, resembling topaz. Also in indistinct embedded crystals, and disseminated masses.

Cleavage: *c* very indistinct. Fracture uneven to subconchoidal. Brittle. H. = 7–7·25. G. = 2·97–3·02. Color pale wine-yellow to colorless, yellowish white, dark wine-yellow, yellowish brown. Luster vitreous to greasy, on crystal surfaces brilliant. Transparent to translucent. Streak white.

Comp. — $CaB_2(SiO_4)_2$ or $CaO.B_2O_3.2SiO_2$ = Silica 48·8, boron trioxide 28·4, lime 22·8 = 100.

Pyr., etc.—B.B. fuses at 3·5 to a colorless glass, and imparts a green color to the O. F. (boron). Not decomposed by hydrochloric acid, but sufficiently attacked for the solution to give the reaction of boric acid with turmeric paper. When previously ignited gelatinizes with hydrochloric acid. Phosphoresces on heating, giving a reddish light.

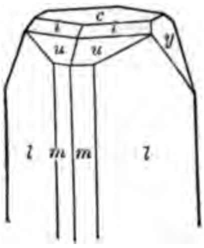
Obs.—Occurs at Danbury, Conn., with microcline and oligoclase in dolomite. At Russell, N. Y., in fine crystals. On the Piz Valatscha, the northern spur of Mt. Skopi south of Dissentis in eastern Switzerland, in slender prismatic crystals.

BARSOWITE. This doubtful species, occurring with blue corundum in the Ural, is by some authors classed with danburite; composition $CaAl_2Si_2O_8$ like anorthite.

TOPAZ.

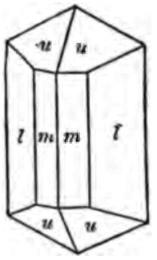
Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}52854 : 1 : 0{\cdot}47698$.

837.



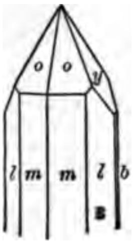
Ural

838.



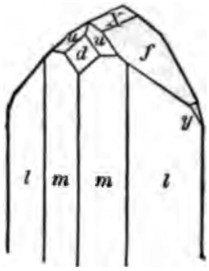
Brazil.

839.



Durango.

840.



Japan.

mm''', $110 \wedge 110 = 55° 43'$.
ll', $120 \wedge \bar{1}20 = 89° 49'$.
dd', $201 \wedge \bar{2}01 = 122° 1'$.
XX', $043 \wedge 0\bar{4}3 = 64° 55'$.
ff', $021 \wedge 0\bar{2}1 = 87° 18'$.

yy', $041 \wedge 0\bar{4}1 = 124° 41'$.
ci, $001 \wedge 223 = 34° 14'$.
cu, $001 \wedge 111 = 45° 35'$.
co, $001 \wedge 221 = 63° 54'$.

uu', $111 \wedge \bar{1}11 = 78° 20'$.
uu''', $111 \wedge 1\bar{1}1 = 39° 0'$.
oo', $221 \wedge \bar{2}21 = 105° 7'$.
oo''' $221 \wedge 2\bar{2}1 = 49° 37\tfrac{1}{2}'$.

Crystals commonly prismatic, *m* predominating; or *l* (120) and the form then a nearly square prism resembling andalusite. Faces in the prismatic zone often vertically striated, and often showing vicinal planes. Also firm columnar; granular, coarse or fine.

Cleavage: *c* highly perfect. Fracture subconchoidal to uneven. Brittle. H. = 8. G. = 3·4–3·6. Luster vitreous. Color straw-yellow, wine-yellow, white, grayish, greenish, bluish, reddish. Streak uncolored. Transparent to subtranslucent. Optically +. Ax. pl. ∥ *b*. Bx ⊥ *c*. Axial angles variable. $2E_y$ = 112° to 120° 40′. Refractive indices, Brazil (Mühlheims):

For D $\alpha = 1·62936$ $\beta = 1·63077$ $\gamma = 1·63747$ $\therefore$ $2V = 49° 31'$

Var.—*Ordinary.* In prismatic crystals usually colorless or pale yellow, less often pale blue, pink, etc. The yellow of the Brazilian crystals is changed by heating to a pale rose-pink. Often contains inclusions of liquid CO_2.

Physalite, or *pyrophysalite*, is a coarse nearly opaque variety, from Finbo; intumesces when heated, hence its name from φυσαλίς, *bubble*, and πῦρ, *fire*. *Pycnite* has a columnar, very compact structure. Rose made out that the cleavage was the same, and the form probably the same; and Des Cloizeaux showed that the optical characters were those of topaz.

Comp.—$(AlF)_2SiO_4$; usually containing hydroxyl and then $[Al(F,OH)]_2SiO_4$ or as given on p. 430. The former requires Silica 32·6, alumina 55·4, fluorine 20·7 = 108·7, deduct (O = 2F) 8·7 = 100.

Pyr., **etc.**—B.B. infusible. Fused in the closed tube, with previously fused and pulverized salt of phosphorus, etches the glass, giving off silicon fluoride, which forms a ring of SiO_2 above. With cobalt solution the pulverized mineral gives a fine blue on heating. Only partially attacked by sulphuric acid. A variety of topaz from Brazil, when heated, assumes a pink or red hue, resembling the Balas ruby.

Diff.—Characterized by its prismatic crystals with angles of 56° (124°) or 87° (93°); also by the perfect basal cleavage; hardness; infusibility; yields fluorine B.B.

Obs.—Topaz occurs especially in the highly acid igneous rocks of the granite family, as granite and rhyolite, in veins and cavities, where it appears to be the result of fumarole action after the crystallization of the magma; sometimes also in the surrounding schists, gneisses, etc., as a result of such action. In these occurrences often accompanied by fluorite, cassiterite, tourmaline.

Fine topaz comes from the Urals, from Alabashka, in the region of Ekaterinburg; from Miask in the Ilmen Mts ; also the gold-washings on the R. Sanarka, in Govt. Orenburg; in Nerchinsk, beyond L. Baikal, in the Adun-Chalon Mts., etc.; in the province of Minas Geraes, Brazil, at Ouro Preto and Villa Rica, of deep yellow color; at the tin mines of Zinnwald and Ehrenfriedersdorf, and smaller crystals at Schneckenstein and Altenberg; sky-blue crystals in Cairngorm, Aberdeenshire; the Mourne mountains, Ireland; on the island of Elba. *Physalite* occurs in crystals of great size, at Fossum, Norway; Finbo, Sweden. *Pycnite* is from the tin mine of Altenberg in Saxony; also of Schlackenwald, Zinnwald, etc. Fine crystals occur at Durango, Mexico, with tin ore; at San Luis Potosi in rhyolite. Mt. Bischoff, Tasmania, with tin ores; similarly in New South Wales. In Japan in pegmatite from Otani-yama, Province of Omi, near Kioto.

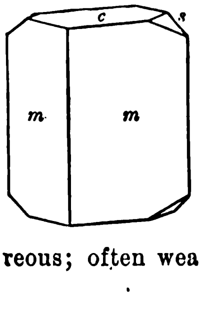
In the United States, in *Maine*, at Stoneham, in albitic granite. In *Conn.*, at Trumbull, with fluorite; at Willimantic. In *N. Car.*, at Crowder's Mountain. In *Colorado*, in fine crystals colorless or pale blue from the Pike's Peak region; at Nathrop, Chaffee Co., in wine-colored crystals with spessartite in lithophyses in rhyolite; similarly in the rhyolite of Chalk Mt. In *Utah*, in fine transparent colorless crystals with quartz and sanidine in the rhyolite of the Thomas Range, 40 miles north of Sevier Lake.

The name topaz is from τοπάζιος, an island in the Red Sea, as stated by Pliny. But the topaz of Pliny was not the true topaz, as it "yielded to the file." Topaz was included by Pliny and earlier writers, as well as by many later, under the name *chrysolite*.

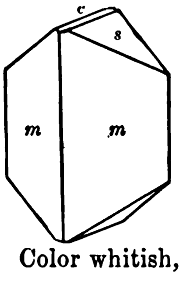
ANDALUSITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·9861 : 1 : 0·70245$.

841.



842.



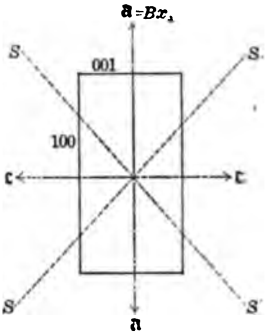
mm''', 110 $\wedge$ 1$\bar{1}$0 = 89° 12'.
ss', 011 $\wedge$ 0$\bar{1}$1 = 70° 10'.

Usually in coarse prismatic forms, the prisms nearly square in form. Massive, imperfectly columnar; sometimes radiated and granular.

Cleavage: *m* distinct, sometimes perfect (Brazil); *a* less perfect: *b* in traces. Fracture uneven, subconchoidal. Brittle. H. = 7·5. G. = 3·16–3·20. Luster vitreous; often weak. Color whitish, rose-red, flesh-red, violet, pearl-gray reddish brown, olive-green. Streak uncolored. Transparent to opaque, usually subtranslucent. Pleochroism strong in some colored varieties. Absorption strong, $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. Sections normal to an optic axis are idiophanous or show the polarization-brushes distinctly (p. 219). Optically −. Ax. pl. ‖ *b*. $Bx \perp c$. $2H_r = 96° 30'$ Brazil; $\beta_r = 1{\cdot}638$; $\gamma - \alpha = 0{\cdot}011$.

Chiastolite, or *Macle* is a variety in stout crystals having the axis and angles of a different color from the rest, owing to a regular arrangement of carbonaceous impurities through the interior, and hence exhibiting a colored cross, or a tesselated appearance in a transverse section. Fig. 844 shows sections of a crystal.

843.



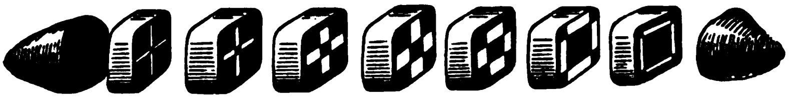
Comp.—$Al_2SiO_5 = (AlO)AlSiO_4$ or $Al_2O_3.SiO_2 =$ Silica 36·8, alumina 63·2 = 100. Manganese is sometimes present, as in manganandalusite.

Pyr., etc.—B.B. infusible. With cobalt solution gives a blue color after ignition, Not decomposed by acids. Decomposed on fusion with caustic alkalies and alkaline carbonates.

Diff.—Characterized by the nearly square prism, pleochroism, hardness, infusibility; reaction for alumina B.B.

Distinguished in thin sections by its high relief; low interference-colors, which are only slightly above those of quartz; negative biaxial character; negative extension of the crystals (diff. from sillimanite); rather distinct prismatic cleavage and the constant parallel extinction (diff. from pyroxenes, which have also greater birefringence); also by its characteristic arrangement of impurities when these are present (Fig. 844). The pleochroism, which is often lacking, is when present strong and characteristic.

844.



Obs.—Most common in argillaceous schist, or other schists imperfectly crystalline; also in gneiss, mica schist and related rocks; rarely in connection with serpentine. The variety chiastolite is commonly a contact mineral in clay-slates, *e.g.*, adjoining granitic dikes. Sometimes associated with sillimanite with parallel axes.

Found in Spain, in Andalusia; in the Tyrol, Lisens Alp; in Saxony, at Bräunsdorf; Bavaria, at Wunsiedel, etc. In Brazil, province of Minas Geraes, in fine crystals and as rolled pebbles.

In N. America, in *Maine*, at Standish. *N. Hamp.*, White Mtn. Notch; *Mass.*, at Westford; Lancaster, both varieties; Sterling, chiastolite. *Conn.*, at Litchfield and Washington. *Penn.*, in Delaware Co., near Leiperville, large cryst.; Upper Providence.

Named from Andalusia, the first locality noted. The name *macle* is from the Latin *macula*, a spot. Chiastolite is from *χιάστος*, *arranged diagonally*, and hence from *chi*, the Greek name for the letter X.

SILLIMANITE. Fibrolite.

Orthorhombic. Axes $\breve{a} : \bar{b} = 0{\cdot}970 : 1$. $mm''' = 88° 15'$, hh' $(230 \wedge \bar{2}30) = 69°$. Prismatic faces striated and rounded. Commonly in long slender crystals not distinctly terminated; often in close parallel groups, passing into fibrous and columnar massive forms; sometimes radiating.

Cleavage: *b* very perfect. Fracture uneven. H. = 6–7. G. = 3·23–3·24. Luster vitreous, approaching subadamantine. Color hair-brown, grayish brown, grayish white, grayish green, pale olive-green. Streak uncolored. Transparent to translucent. Pleochroism sometimes distinct. Optically +.

Double refraction strong. Ax. pl. ∥ b. Bx ⊥ c. Dispersion $\rho > v$. $2E_r = 44°$. $\beta = 1·661$; $\gamma - \alpha = 0·021$.

Pyr.—Same as andalusite.

Diff.—Characterized by its fibrous or columnar form; perfect cleavage; infusibility; reaction for alumina.

In thin sections recognized by its form, usually with transverse fractures; parallel extinction; high interference-colors.

Obs.—Often present in the quartz of gneisses and sometimes granites in very slender, minute prisms commonly aggregated together and sometimes intergrown with andalusite; iolite is also a common associate; rarely as a contact mineral; often occurs with corundum.

Observed in many localities, thus near Moldau in Bohemia (*Faserkiesel*); at Fassa in Tyrol (*bucholzite*); in the Carnatic with corundum (*fibrolite*); at Bodenmais, Bavaria; Freiberg, Saxony; in France, near Pontgibaud, and other points in Auvergne; forms rolled masses in the diamantiferous sands of Minas Geraes, Brazil.

In the United States, in *Massachusetts*, at Worcester. In *Connecticut*, near Norwich, with zircon, monazite and corundum; at Willimantic. In *N. York*, at Yorktown, Westchester Co.; in Monroe, Orange Co. (*monrolite*). In *Penn.*, at Chester on the Delaware, near Queensbury forge; in Delaware Co.; *Delaware*, at Brandywine Springs. With corundum in *N. Carolina*.

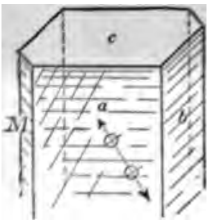
Named *fibrolite* from the fibrous massive variety (*Germ.*, Faserkiesel); *sillimanite*, after Prof. Benjamin Silliman of New Haven (1779–1864).

Bamlite, *xenolite*, *wörthite* probably belong to sillimanite; the last is altered.

CYANITE. Kyanite. Disthene.

Triclinic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·8994 : 1 : 0·7090$; $\alpha = 90° 5\frac{1}{2}'$, $\beta = 101° 2'$, $\gamma = 105° 44\frac{1}{2}'$. ac, 100 ∧ 001 = 78° 30′; bc, 010 ∧ 001 = 86° 45′;

846.



Usually in long bladed crystals, rarely terminated. Also coarsely bladed columnar to subfibrous.

Cleavage: a very perfect; b less perfect; also parting ∥ c. **H.** = 5–7·25; the least, 4–5, on a ∥ $\dot{c}$; 6–7 on a ∥ edge a/c; 7 on b. G. = 3·56–3·67. Luster vitreous to pearly. Color blue, white; blue along the center of the blades or crystals with white margins; also gray, green, black. Streak uncolored. Translucent to transparent. Pleochroism distinct in colored varieties. Optically −. Ax. pl. nearly ⊥ a and inclined to edge a/b on a about 30°, and about 7½ on b. $2H_{a.r} = 99° 18'$ Pfitschthal.

Comp.—Empirical formula Al_2SiO_5 or $Al_2O_3.SiO_2$, like andalusite and sillimanite. Perhaps a basic metasilicate, $(AlO)_2SiO_3$.

Pyr., etc.—Same as for andalusite. At a high temperature (1320°-1380°) cyanite assumes the physical characters of sillimanite.

Diff.—Characterized by the bladed form; common blue color; varying hardness; infusibility; reaction for alumina.

Obs.—Occurs principally in gneiss and mica schist (both the ordinary variety with muscovite and also that with paragonite) often accompanied by garnet and sometimes by staurolite; also in eclogite. It is often associated with corundum.

Found in transparent crystals at Monte Campione in the St. Gothard region in Switzerland in paragonite schist; on Mt. Greiner, Zillerthal, and in the Pfitschthal (*rhætizite*, white) in Tyrol; in eclogite of the Saualpe, Carinthia; Horrsjöberg in Wermland, Sweden; Villa Rica, Brazil, etc.

In *Mass.*, at Chesterfield, with garnet in mica schist. In *Conn.*, at Litchfield and Washington. In *Vermont*, at Thetford. In *Penn.*, in Chester Co. and in Delaware Co. In *Virginia*, Buckingham Co. In *N. Carolina*, with rutile, lazulite, etc., at Crowder's Mt., Gaston Co.; in Gaston and Rutherford counties associated with corundum, damourite; beautiful clear green in Yancey Co. Named from κυανός, *blue*.

Datolite Group. Monoclinic.

Basic Orthosilicates. $H\overset{II}{R}\overset{III}{R}SiO_5$ or $\overset{II}{R}_2\overset{III}{R}_2(SiO_5)_2$. Oxygen ratio for R : Si = 3 : 2.
$\overset{II}{R}$ = Ca,Be,Fe, chiefly; $\overset{III}{R}$ = Boron, the yttrium (and cerium) metals, etc.

	$\grave{a} : \bar{b} : \acute{c}$	β
Datolite	0·6345 : 1 : 1·2657	89° 51′
$HCaBSiO_5$ or $Ca(BOH)SiO_4$		
Homilite	0·6249 : 1 : 1·2824	89° 21′
$Ca_2FeB_2Si_2O_{10}$ or $Ca_2Fe(BO)_2(SiO_4)_2$		
	$2\grave{a} : \bar{b} : 4\acute{c}$	β
Euclase	0·6474 : 1 : 1·3330	79° 44′
$HBeAlSiO_5$ or $Be(AlOH)SiO_4$	$\grave{a}$	
Gadolinite	0·6273 : 1 : 1·3215	89° 26½′
$Be_2FeY_2Si_2O_{10}$ or $Be_2Fe(YO)_2(SiO_4)_2$		

The species of the DATOLITE GROUP are usually regarded as basic orthosilicates, the formulas being taken in the second form given above. They all crystallize in monoclinic system, and all but Euclase conform closely in axial ratio; with the latter there is also a distinct morphological relationship.

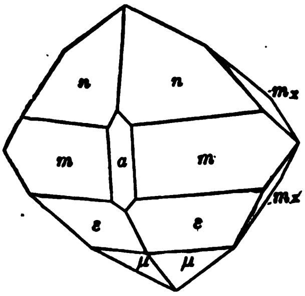
DATOLITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c}$ = 0·6345 : 1 : 1·2657; β = 89° 51⅓′.

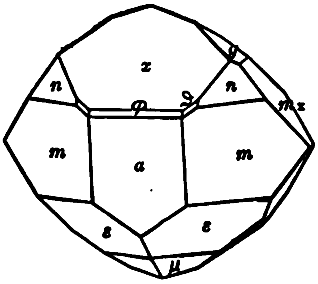
mm‴,	$110 \wedge 1\bar{1}0$ = 64° 47′.	*cn*,	$001 \wedge 111$ = 66° 57′.
ac,	$100 \wedge 001$ = 89° 51′.	*cm*,	$001 \wedge 110$ = 89° 53′.
ax,	$100 \wedge 101$ = 45° 0′.	*cε*,	$001 \wedge \bar{1}12$ = 49° 49′.
gg′,	$012 \wedge 0\bar{1}2$ = 64° 39⅓′.	*nn′*,	$111 \wedge 1\bar{1}1$ = 59° 4⅓′.
$m_x m_x'$,	$011 \wedge 0\bar{1}1$ = 103° 23′.	*εε′*,	$\bar{1}12 \wedge \bar{1}\bar{1}2$ = 48° 19⅓′.

Crystals varied in habit; usually short prismatic with either *m* or m_x predominating; sometimes tabular ‖ *x* (201); also of other types, and often highly modified (Figs. 846–849). Also botryoidal and globular, having a columnar structure; divergent and radiating; sometimes massive, granular to compact and crypto-crystalline.

846.



847.



Bergen Hill.

Cleavage not observed. Fracture conchoidal to uneven. Brittle. H. = 5–5·5. G. = 2·9–3·0. Luster vitreous, rarely subresinous on a surface of fracture. Color white; sometimes grayish, pale green, yellow, red, or amethystine, rarely dirty olive-green or honey-yellow. Streak white. Transparent to translucent; rarely opaque white.

Var.—1. *Ordinary.* In glassy crystals of varied habit, usually with a greenish tinge. The angles in the prismatic and clinodome zones vary but little, e.g., 110 ∧ $\bar{1}$10 = 64° 47′, while 011 ∧ 01$\bar{1}$ = 66° 37′, etc. 2. *Compact massive.* White opaque cream-colored, pink; breaking with the surface of porcelain or Wedgewood ware. From the L. Superior region. 3. *Botryoidal; Botryolite.* Radiated columnar, having a botryoidal surface, and containing more water than the crystals, but optically identical.

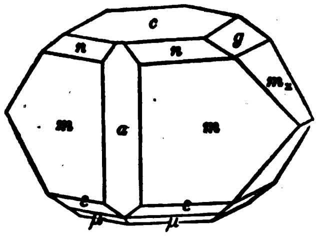
Comp.—A basic orthosilicate of boron and calcium; empirically $HCaBSiO_5$, or $H_2O.2CaO.B_2O_3.2SiO_2$; this may be written $Ca(BOH)SiO_4$ = Silica 37·6, boron trioxide 21·8, lime 35·0, water 5·6 = 100.

Pyr., etc.—In the closed tube gives off much water. B B. fuses at 2 with intumescence to a clear glass, coloring the flame bright green. Gelatinizes with hydrochloric acid.

Diff.—Characterized by its glassy, greenish, complex crystals; easy fusibility and green flame B B.

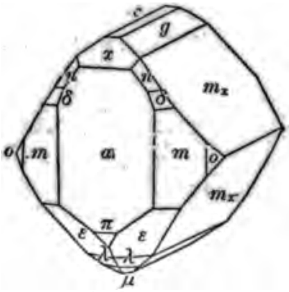
Obs.—Datolite is found chiefly as a secondary mineral in veins and cavities in basic eruptive rocks, often associated with calcite, prehnite and various zeolites; sometimes associated with danburite; also in gneiss, diorite, and serpentine; in metallic veins; sometimes in beds of iron ore. Found in Scotland, in trap, at the Kilpatrick Hills, etc.; in a bed of magnetite at Arendal in Norway (*botryolite*); at Utö in Sweden; at Andreasberg in diabase and in veins of silver ores; in Rhenish Bavaria (the *humboldtite*); at the Seisser Alp, Tyrol, and at Theiss, near Claussen, in geodes in amygdaloid; in granite at Baveno near Lago Maggiore; at Toggiana in Modena, in serpentine; Monte Catini in Tuscany.

848.



Bergen Hill.

849.



Andreasberg.

In the U. S. not uncommon with the diabase of Connecticut and Massachusetts. Thus at the Rocky Hill quarry, Hartford, Conn.; at Middlefield Falls and Roaring Brook, Conn. In N. Jersey, at Bergen Hill, in splendid crystals; at Paterson, Passaic Co. Both crystals and the opaque compact variety, in the Lake Superior region.

Named from *δατεῖσθαι, to divide*, alluding to the granular structure of a massive variety.

Homilite. $(Ca.Fe)_3B_2Si_2O_{10}$ or $(Ca,Fe)_3(BO)_2(SiO_4)_2$. Crystals often tabular ‖ *c*; angles near those of datolite. H. = 5. G. = 3·38. Color black, blackish brown. Found on the island Stokö and other islands, in the Langesund fiord, Norway.

Euclase. $HBeAlSiO_5$ or $Be(AlOH)SiO_4$. In prismatic crystals. Cleavage: *b*(010) perfect. H. = 7·5. G = 3·05–3·10. Luster vitreous. Colorless to pale green or blue. From Brazil, in the province of Minas Geraes; in the auriferous sands of the Orenburg district, southern Ural, near the river Sanárka; in the Glossglockner region of the Austrian Alps.

Gadolinite. $Be_2FeY_2Si_2O_{10}$ or $Be_2Fe(YO)_2SiO_4)_2$. Crystals, often prismatic, rough and coarse; commonly in masses. Cleavage none. Fracture conchoidal or splintery. Brittle. H. = 6·5–7. G. = 4·0–4·5; normally 4·36–4·47 (anisotropic), 4·24–4·29 (isotropic and amorphous from alteration). Luster vitreous to greasy. Color black, greenish black, also brown. From near Falun and Ytterby, Sweden; Hitterö, Norway; also in Llano Co., Texas, in nodular masses and rough crystals, sometimes up to 40 or 60 pounds in weight.

The yttrium earths or "gadolinite-earths" (partly replaced by the oxides of cerium, lanthanum and didymium) form a complex group which contains considerable erbium, also several new elements (ytterbium, scandium, etc.) of more or less definite character.

Yttrialite. A silicate of thorium and the yttrium metals chiefly. Massive; amorphous. G. = 4·575. Color on the fresh fracture olive-green, changing to orange-yellow on surface. Associated with the gadolinite of Llano Co., Texas.

Rowlandite. An yttrium silicate, occurring massive with gadolinite of Llano Co., Texas; color drab-green.

Mackintoshite. Silicate of uranium, thorium, cerium, etc. Massive. Color black. Llano Co., Texas

---

Epidote Group. Orthorhombic and Monoclinic.

Basic Orthosilicates, $H\overset{II}{R}_2\overset{III}{R}_3Si_3O_{13}$ or $\overset{II}{R}_2(\overset{III}{R}OH)\overset{III}{R}_2(SiO_4)_3$,
$\overset{II}{R} = Ca,\overset{II}{Fe}$; $\overset{III}{R} = Al,\overset{III}{Fe},\overset{III}{Mn},Ce$, etc.

α. Orthorhombic Section.

		$\breve{a} : \bar{b} : \dot{c}$
Zoisite	$Ca_2(AlOH)Al_2(SiO_4)_3$	0·6196 : 1 : 0·3429

β. Monoclinic Section.

		$\grave{a} : b : \dot{c}$	
Epidote	$\begin{cases} mCa_2(AlOH)Al_2(SiO_4)_3 \\ nCa_2(FeOH)Fe_2(SiO_4)_3 \end{cases}$	1·5787 : 1 : 1·8036	64° 37′
Piedmontite	$Ca_2(AlOH)(Al,Mn)_2(SiO_4)_3$	1·6100 : 1 : 1·8326	64° 39′
Allanite	$(Ca,Fe)_2(AlOH)(Al,Ce,Fe)_2(SiO_4)_3$	1·5509 : 1 : 1·7691	64° 59′

The EPIDOTE GROUP includes the above complex orthosilicates. The monoclinic species agree closely in form. To them the orthorhombic species zoisite is also related in angle, its prismatic zone corresponding to the monoclinic orthodomes, etc. Thus we have:

Zoisite *mm‴*, 110 ∧ 110 = 63° 34′. Epidote *cr*, 001 ∧ $\bar{1}$01 = 63° 42′.
uu′, 021 ∧ 0$\bar{2}$1 = 68° 54′. *mm′*, 110 ∧ $\bar{1}$10 = 70° 4′, etc.

There seems to be, however, a monoclinic calcium compound, having the composition of zoisite, but monoclinic and strictly isomorphous with ordinary epidote; it is called *clinozoisite.*

ZOISITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·6196 : 1 : 0·34295.

mm‴, 110 ∧ 1$\bar{1}$0 = 63° 34′. *ff′*, 011 ∧ 0$\bar{1}$1 = 37° 52′.
dd′, 101 ∧ $\bar{1}$01 = 57° 56′. *oo‴*, 111 ∧ 1$\bar{1}$1 = 33° 24′.

Crystals prismatic, deeply striated or furrowed vertically, and seldom distinctly terminated. Also massive; columnar to compact.

Cleavage: *b* very perfect. Fracture uneven to subconchoidal. Brittle. H. = 6–6·5. G. = 3·25–3·37. Luster vitreous; on the cleavage-face, *b*, pearly. Color grayish white, gray, yellowish brown, greenish gray, apple-green; also peach-blossom-red to rose-red. Streak uncolored. Transparent to subtranslucent.

Pleochroism strong in pink varieties. Optically +. Ax. pl. usually ∥ *b*; also ∥ *c*. Bx ⊥ *a*. Dispersion strong, $\rho < v$; also $\rho > v$. Axial angle variable even in the same crystal. $2E_r = 42°–90°$. $\beta = 1·696$; $\gamma - \alpha = 0·006$.

Var.—1. *Ordinary.* Colors gray to white and brown; also green. Usually in indistinct prismatic or columnar forms; also in fibrous aggregates. G. = 3·226–3·381. *Unionite* is a very pure zoisite. 2. *Rose-red* or *Thulite.* Fragile; pleochroism strong. 3. *Compact, massive.* Includes the essential part of most saussurite (*e.g.*, in saussurite-gabbro), which has arisen from the alteration of feldspar.

Comp.—$HCa_2Al_3Si_3O_{13}$ or $4CaO.3Al_2O_3.6SiO_2.H_2O$ = Silica 39·7, alumina 33·7, lime 24·6, water 2·0 = 100. The alumina is sometimes replaced by iron, thus graduating toward epidote, which has the same general formula.

Pyr., etc.—B.B. swells up and fuses at 3–3·5 to a white blebby mass. Not decomposed by acids; when previously ignited gelatinizes with hydrochloric acid. Gives off water when strongly ignited.

Diff.—Characterized by the columnar structure; fusibility with intumescence; resembles some amphibole.

Distinguished in thin sections by its high relief and very low interference-colors; lack of color and biaxial character. From epidote it is distinguished by its lack of color and low birefringence; from vesuvianite by its color and biaxial character. Thin sections frequently show the "*ultra blue*" (p. 428) between crossed nicols.

Obs.—Occurs especially in those crystalline schists which have been formed by the dynamic metamorphism of basic igneous rocks containing plagioclase rich in lime. Commonly accompanies some one of the amphiboles (actinolite, smaragdite, glaucophane, etc.); thus in amphibolite, glaucophane schist, eclogite; often associated with corundum.

The original zoisite is that of the eclogite of the Saualpe in Carinthia (*saualpite*). Other localities are: Rauris in Salzburg; Sterzing, etc., in Tyrol; the Fichtelgebirge in Bavaria; Marschendorf in Moravia; Saasthal in Switzerland; the island of Syra, one of the Cyclades, in glaucophane schist. *Thulite* occurs at Kleppau in Tellemarken, Norway, and at Traversella in Piedmont.

EPIDOTE. Pistacite. Pistazit, *Germ.*

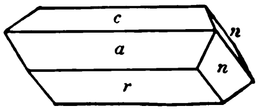
Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c}$ = 1·5787 : 1 : 1·8036; β = 64° 37′.

mm‴, 110 $\wedge$ $1\bar{1}0$ = 109° 56′.
ca, 001 $\wedge$ 100 = 64° 37′.
ce, 001 $\wedge$ 101 = 34° 43′.
cr, 001 $\wedge$ $\bar{1}01$ = 63° 42′.
ar′, 100 $\wedge$ $10\bar{1}$ = 51° 41′.

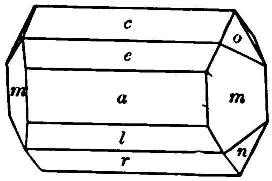
cl, 001 $\wedge$ $\bar{2}01$ = 89° 26′.
co, 001 $\wedge$ 011 = 58° 28′.
cn, 001 $\wedge$ $\bar{1}11$ = 75° 11′.
an‴, 100 $\wedge$ $11\bar{1}$ = 69° 2′.
nn‴, $\bar{1}11$ $\wedge$ $11\bar{1}$ = 70° 29′.

Twins: tw. pl. *a* common, often as embedded tw. lamellæ. Crystals usually prismatic ‖ the ortho-axis $\bar{b}$ and terminated at one extremity only; passing into acicular forms; the faces in the zone *ac* deeply striated. Also fibrous, divergent or parallel; granular, particles of various sizes, sometimes fine-granular, and forming rock-masses.

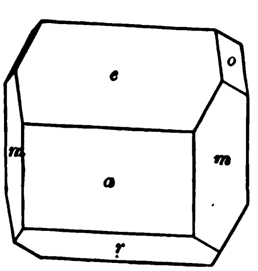
850.



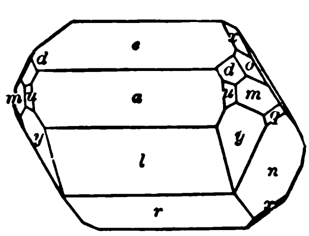
851.



852.

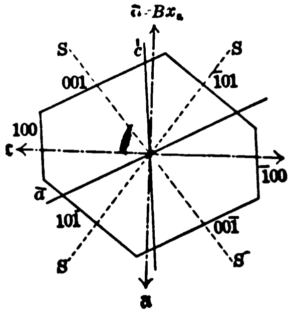


853.



Cleavage: *c* perfect; *a* imperfect. Fracture uneven. Brittle. H. = 6–7. G. = 3·25–3·5. Luster vitreous; on *c* inclining to pearly or resinous. Color pistachio-green or yellowish green to brownish green, greenish black, and black; sometimes clear red and yellow; also gray and grayish white, rarely colorless. Streak uncolored, grayish. Transparent to opaque: generally subtranslucent.

854.



Pleochroism strong: vibrations ∥ c green, b brown and strongly absorbed, a yellow. Absorption usually b > c > a; but sometimes c > b > a in the variety of epidote common in rocks. Often exhibits idiophanous figures; best in sections normal to an optic axis, but often to be observed in natural crystals (Sulzbach), especially if flattened ∥ *r* ($\bar{1}01$). (See p. 218.) Optically –. Ax. pl. ∥ *b*. $Bx._{a.r} \wedge \dot{c} = -2° 56'$. Hence c ⊥ *a* (100) nearly. Dispersion inclined, strongly marked; of the axes feeble, $\rho > v$. $2\dot{H}_{a.y} = 91° 20'$. $\beta_y = 1{\cdot}75702$. Birefringence high, $\gamma - \alpha = 0{\cdot}038 - 0{\cdot}056$.

Var.—Epidote has ordinarily a peculiar yellowish green (pistachio) color, seldom found in other minerals. But this color passes into dark and light shades—black on one side and brown on the other; red, yellow and colorless varieties also occur.

Var. 1. *Ordinary.* Color green of some shade, as described, the pistachio tint rarely absent. (*a*) In crystals. (*b*) Fibrous. (*c*) Granular massive. (*d*) *Scorza* is epidote sand from the gold washings in Transylvania. The Arendal epidote (*Arendalite*) is mostly in dark green crystals; that of Bourg d'Oisans Dauphiné (*Thallite*, *Delphinite*, *Oisanite*) in yellowish-green crystals, sometimes transparent. *Puschkinite* includes crystals from the auriferous sands of Ekaterinburg, Ural. *Achmatite* is ordinary epidote from Achmatovsk, Ural. A variety from Garda, Hoste Is., Terra del Fuego, is colorless and resembles zoisite.

2. The *Bucklandite* from Achmatovsk, described by Hermann, is black with a tinge of green, and differs from ordinary epidote in having the crystals nearly symmetrical and not, like other epidote, lengthened in the direction of the orthodiagonal. G. = 3·51.

3. *Withamite.* Carmine-red to straw-yellow, strongly pleochroic; deep crimson and straw-yellow. H. = 6–6·5; G. = 3·137; in small radiated groups. From Glencoe, in Argyleshire, Scotland. Sometimes referred to piedmontite, but contains little MnO.

Comp.—$HCa_2(Al,Fe)_3Si_3O_{13}$ or $H_2O.4CaO.3(Al,Fe_2)_2O_3.6SiO_2$, the ratio of aluminium to iron varies commonly from 6 : 1 to 3 : 2. Percentage composition:

For Al : Fe = 3 : 1 SiO_2 37·87, Al_2O_3 24·13, Fe_2O_3 12·60, CaO 23·51, H_2O 1·89 = 100

Clinozoisite is an epidote without iron, having the composition of zoisite; *fouqueite* is probably the same from an anorthite-gneiss in Ceylon. *Picroepidote* is supposed to contain Mg in place of Ca.

Pyr., etc.—In the closed tube gives water on strong ignition. B.B. fuses with intumescence at 3–3·5 to a dark brown or black mass which is generally magnetic. Reacts for iron and sometimes for manganese with the fluxes. Partially decomposed by hydrochloric acid, but when previously ignited, gelatinizes with acid. Decomposed on fusion with alkaline carbonates.

Diff.—Characterized often by its peculiar yellowish-green (pistachio) color; readily fusible and yields a magnetic globule B.B. Prismatic forms often longitudinally striated, but they have not the angle, cleavage or brittleness of tremolite; tourmaline has no distinct cleavage, is less fusible (in common forms) and usually shows its hexagonal form.

Recognized in thin sections by its high refraction; strong interference-colors rising into those of the third order in ordinary sections; decided color and striking pleochroism; also by the fact that the plane of the optic axes lies transversely to the elongation of the crystals.

Obs.—Epidote is commonly formed by the metamorphism (both local igneous and of general dynamic character) of impure calcareous sedimentary rocks or igneous rocks containing much lime. It thus often occurs in gneissic rocks, mica schist, amphibole schist, serpentine; so also in quartzites and sandstones altered by neighboring igneous rocks. Often accompanies beds of magnetite or hematite in such rocks. Has also been found in granite (Hobbs, Maryland), and regarded as an original mineral.

It is often associated with quartz, feldspar, actinolite, axinite, chlorite, etc. It sometimes forms with quartz an epidote rock, called *epidosite*. A similar rock exists at Melbourne in Canada. A gneissoid rock consisting of flesh-colored orthoclase, quartz and epidote from the Unaka Mts. (N. C. and Tenn.) has been called unakyte.

Beautiful crystallizations come from Bourg d'Oisans, Dauphiné; the Ala valley and Traversella, in Piedmont; Elba; Zermatt; Zillerthal in Tyrol; also in fine crystals from the Knappenwand in the Untersulzbachthal, Pinzgau, associated with asbestus, adularia, apatite, titanite, scheelite; further at Striegau, Silesia; Zöptau, Moravia; Arendal, Norway; the Achmatovsk mine near Zlatoust, Ural.

In N. America, occurs in *N. Hamp.*, at Franconia. In *Mass.*, at Hadlyme and Chester, in crystals in gneiss; at Athol, in syenitic gneiss, in fine crystals, 2 m. S. W. of the center of the town; Newbury, in limestone. In *Conn.*, at Haddam, in large splendid crystals. In *N. York*, near Amity; Monroe, Orange Co.; Warwick, pale yellowish green, with titanite and pyroxene. In *N. Carolina*, at Hampton's, Yancey Co.; White's mill, Gaston Co.; Franklin, Macon Co.; in crystals and crystalline masses in quartz at White Plains, Alexander Co. In *Michigan*, in the Lake Superior region, at many of the mines.

Epidote was named by Haüy, from the Greek ἐπίδοσις, *increase*, translated by him, "qui à reçu un accroissement," the base of the prism (rhomboidal prism) having one side longer than the other. *Pistacite*, from πιστακια, *the pistachio-nut*, refers to the color.

Piedmontite. Similar in angle to ordinary epidote, but contains 5 to 15 p. c. Mn_2O_3. H. = 6·5. G. = 3·404. Color reddish brown and reddish black. Pleochroism strong. Absorption $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. Optically +. Ax. pl. ‖ *b*. $Bx_{a.r} \wedge \dot{c} = +82° 34'$, $\mathfrak{a} \wedge \dot{c} = -6°$ to $-3°$. Occurs with manganese ores at St. Marcel, Piedmont. In crystalline schists on Ile de Groix, France; in glaucophane-schist, in Japan. Occasionally in quartz porphyry, as in the antique red porphyry of Egypt, also that of South Mountain, Penn.

ALLANITE. Orthite.

Monoclinic. Axes, p. 437. In angle near epidote. Crystals often tabular ‖ *a*; also long and slender to acicular prismatic by elongation ‖ axis $\bar{b}$. Also massive and in embedded grains.

Cleavage: *a* and *c* in traces; also *m* sometimes observed. Fracture uneven or subconchoidal. Brittle. H. = 5·5–6. G. = 3·0–4·2. Luster submetallic, pitchy or resinous. Color brown to black. Subtranslucent to opaque. Pleochroism strong: $\mathfrak{c}$ brownish yellow, $\mathfrak{b}$ reddish brown, $\mathfrak{a}$ greenish brown. Optically −. Ax. pl. ‖ *b*. $Bx_a \wedge \dot{c} = 32\frac{1}{2}°$ approx. $\beta = 1·682$. Birefringence low; $\gamma - \alpha = 0·032$. Also isotropic and amorphous by alteration analogous to gadolinite.

Var.—*Allanite.* The original mineral was from East Greenland, in tabular crystals or plates. Color black or brownish black. G. = 3·50–3·95. *Bucklandite* is anhydrous allanite in small black crystals from a magnetite mine near Arendal, Norway. *Bagrationite* occurs in black crystals which are like the bucklandite of Achmatovsk (epidote).

Orthite included, in its original use, the slender or acicular prismatic crystals, containing some water, from Finbo, near Falun, Sweden. But these graduate into massive forms, and some orthites are anhydrous, or as nearly so as most allanite. The name is from ὀρθός, *straight*.

Comp.—Like epidote $H\overset{II}{R}_2\overset{III}{R}_3Si_3O_{13}$ or $H_2O.4RO.3R_2O_3.6SiO_2$ with $\overset{II}{R} = Ca$ and Fe, and $\overset{III}{R} =$ Al, Fe, the cerium metals Ce, Di, La, and in smaller amounts those of the yttrium group. Some varieties contain considerable water, but probably by alteration.

Pyr., **etc.**—Some varieties give much water in the closed tube, and all kinds yield a small amount on strong ignition. B.B. fuses easily and swells up (F. = 2·5) to a dark, blebby, magnetic glass. With the fluxes reacts for iron. Most varieties gelatinize with hydrochloric acid, but if previously ignited are not decomposed by acid.

Obs.—Occurs in albitic and common feldspathic granite, gneiss, syenite, zircon-syenite, porphyry. Thus in Greenland ; Norway ; Sweden ; Striegau, Silesia Also in white limestone as at Auerbach on the Bergstrasse ; often in mines of magnetic iron. Rather common as an accessory constituent in many rocks, as in andesite, diorite, dacite, rhyolite, the tonalite of Mt. Adamello, the scapolite rocks of Ödegaarden, Norway, etc. Sometimes inclosed as a nucleus in crystals of the isomorphous species, epidote.

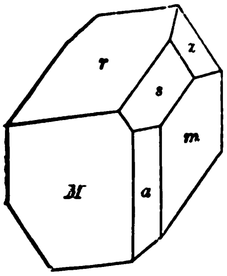
At Vesuvius in ejected masses with sanidine, sodalite, nephelite, hornblende, etc. Similarly in trachytic ejected masses at the Laacher See (*bucklandite*).

In *Mass.*, at the Bolton quarry. In *N. York*, Moriah, Essex Co., with magnetite and apatite ; at Monroe, Orange Co. In *N. Jersey*, at Franklin Furnance with feldspar and magnetite. In *Penn.*, at S. Mountain, near Bethlehem, in large crystals ; at E. Bradford ; near Eckhardt's furnace, Berks Co., abundant. In *Virginia*, in large masses in Amherst Co.; also in Bedford, Nelson, and Amelia counties. In *N. Carolina*, at many points. At the Devil's Head Mt., Douglas Co , Colorado.

AXINITE.

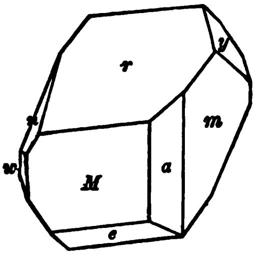
Triclinic. Axes $\breve{a} : \bar{b} : \acute{c} = 0{\cdot}4921 : 1 : 0{\cdot}4797$; $\alpha = 82° 54'$, $\beta = 91° 52'$, $\gamma = 131° 32'$.

855.



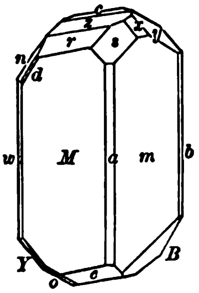
Dauphiné.

856.



Poloma.

857.



Bethlehem, Pa.

am, 100 ∧ 100 = 15° 34'.
aM, 100 ∧ 1$\bar{1}$0 = 28° 55'.
as, 100 ∧ 201 = 21° 37'.
Mr, 1$\bar{1}$0 ∧ 1$\bar{1}$1 = 45° 15'.
mr, 110 ∧ 1$\bar{1}$1 = 64° 22'.
ms, 110 ∧ 201 = 27° 57'.

Crystals usually broad and acute-edged, but varied in habit. Also massive, lamellar, lamellæ often curved ; sometimes granular.

Cleavage : *b* distinct. Fracture conchoidal. Brittle. H. = 6·5–7. G. = 3·271–3·294. Luster highly glassy. Color clove-brown, plum-blue, and pearl-gray ; also honey-yellow, greenish yellow. Streak uncolored. Transparent to subtranslucent. Pleochroism strong. Optically —. Ax. pl. and Bx_a approximately ⊥ *x* (111). Axial angles variable. $2H_{a.r} = 87° 30'$; $\beta_r = 1{\cdot}678$. Pyroelectric (p. 234).

Comp.—A boro-silicate of aluminium and calcium with varying amounts of iron and manganese. Perhaps $H_2R_4(BO)Al_3(SiO_4)_5$ (Whitfield.) R = Calcium chiefly, sometimes in large excess, again in smaller amount and manganese prominent ; iron is present in small quantity, also magnesium and basic hydrogen.

Analyses. 1, Whitfield ; 2, Genth.

	G.	SiO_2	B_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	ign.	
1. Bourg d'Oisans		41·53	4·62	17·90	3·90	4·02	3·79	21·66	0·74	2·16	= 100·32
2. Franklin, *cryst.*	3·358	42·77	5·10	16·73	1·03	1·60*	13·69	18·25	0·28	0·76	= 100·16

*ZnO, including 0·12 CuO.

Pyr., etc.—B.B. fuses readily with intumescence, imparts a pale green color to the O.F., and fuses at 2 to a dark green to black glass; with borax in O.F gives an amethystine bead (manganese), which in R.F. becomes yellow (iron). Fused with a mixture of bisulphate of potash and fluor on the platinum loop colors the flame green (boric acid). Not decomposed by acids, but when previously ignited, gelatinizes with hydrochloric acid.

Obs.—Axinite occurs in clove-brown crystals, near Bourg d'Oisans in Dauphiné; at Andreasberg; Striegau, Silesia; on Mt. Skopi, in eastern Switzerland; Elba; at the silver mines of Kongsberg, Norway; Nordmark, Sweden; near Miask in the Ural; in Cornwall, of a dark color, at the Botallack mine near St. Just, etc.

In the U. S., at Phippsburg, Maine; Franklin Furnace, N. J., honey-yellow; at Bethlehem, Pa.

Named from *ἀξίνη, an axe*, in allusion to the form of the crystals.

PREHNITE.

Orthorhombic-hemimorphic. Axes $\breve{a} : \bar{b} : \acute{c}$ = 0·8401 : 1 : 0·5549.

Distinct individual crystals rare; usually tabular ∥ *c*; sometimes prismatic *mm'''* = 80° 4'; again acute pyramidal. Commonly in groups of tabular crystals, united by *c* making broken forms, often barrel-shaped. Reniform, globular, and stalactitic with a crystalline surface. Structure imperfectly columnar or lamellar, strongly coherent; also compact granular or impalpable.

Cleavage: *c* distinct. Fracture uneven. Brittle. H. = 6–6·5. G. = 2·80–2·95. Luster vitreous; *c* weak pearly. Color light green, oil-green, passing into white and gray; often fading on exposure. Subtransparent to translucent. Streak uncolored.

Comp.—An acid orthosilicate, $H_2Ca_2Al_2(SiO_4)_3$ = Silica 43·7, alumina 24·8, lime 27·1, water 4·4 = 100.

Prehnite is sometimes classed with the zeolites, with which it is often associated; the water here, however, has been shown to go off only at a red heat, and hence plays a different part.

Pyr., etc.—In the closed tube yields water. B.B. fuses at 2 with intumescence to a blebby enamel-like glass. Decomposed slowly by hydrochloric acid without gelatinizing; after fusion dissolves readily with gelatinization.

Diff.—B.B. fuses readily, unlike beryl, green quartz, and chalcedony. Its hardness is greater than that of the zeolites.

Obs.—Occurs chiefly in basic eruptive rocks, basalt, diabase, etc., as a secondary mineral in veins and cavities, often associated with some of the zeolites, also datolite, pectolite, calcite, but commonly one of the first formed of the series; also less often in granite, gneiss, syenite, and then frequently associated with epidote; sometimes associated with native copper, as in the L. Superior region.

At St. Christophe, near Bourg d'Oisans in Dauphiné; Fassathal, Tyrol; the Ala valley in Piedmont; in the Harz, near Andreasberg; in granite at Striegau, Silesia; Arendal, Norway; Ædelfors in Sweden (*edelite*); at Corstorphine Hill, near Edinburgh; Mourne Mts., Ireland.

In the United States, finely crystallized at Farmington, Conn.; Paterson and Bergen Hill, N. J.; in syenite, at Somerville, Mass.; on north shore of Lake Superior, and the copper region.

Named (1790) after Col. Prehn, who brought the mineral from the Cape of Good Hope.

Harstigite. An acid orthosilicate of manganese and calcium. In small colorless prismatic crystals. H. = 5·5. G. = 3·049. From the Harstig mine, near Pajsberg, Wermland, Sweden.

Cuspidine. Contains silica, lime, fluorine, and from alteration carbon dioxide; formula doubtful. In minute spear-shaped crystals H. = 5-6. G. = 2·853–2·860. Color pale rose-red. From Vesuvius, in ejected masses in the tufa of Monte Somma.

IV. Subsilicates.

The species here included are basic salts, for the most part to be referred either to the metasilicates or orthosilicates, like many basic compounds already included in the preceding pages. Until their constitution is definitely settled, however, they are more conveniently grouped by themselves as SUBSILICATES.

It may be noted that those species having an oxygen ratio of silicon to bases of 2 : 3, like topaz, andalusite, sillimanite, datolite, etc., also calamine, carpholite, and perhaps tourmaline, are sometimes regarded as salts of the hypothetical parasilicic acid, H_6SiO_5.

The only prominent group in this subdivision is the HUMITE GROUP.

Humite Group.

			$\grave{a} : \bar{b} : \dot{c}$	β
Prolectite	$[Mg(F,OH)]_2Mg[SiO_4]_1$?	Monoclinic	1·0803 : 1 : 1·8861	90°
Chondrodite	$[Mg(F,OH)]_2Mg_3[SiO_4]_2$	Monoclinic	1·0863 : 1 : 3·1447	90°
			$\bar{b} : \breve{a} : \dot{c}$	
Humite	$[Mg(F,OH)]_2Mg_5[SiO_4]_3$	Orthorhombic	1·0802 : 1 : 4·4033	—
Clinohumite	$[Mg(F,OH)]_2Mg_7[SiO_4]_4$	Monoclinic	1·0803 : 1 : 5·6588	90°

The species here included form a remarkable series both as regards crystalline form and chemical composition. In crystallization they have sensibly the same ratio for the lateral axes, while the vertical axes are almost exactly in the ratio of the numbers 3 : 5 : 7 : 9 (see also below). Furthermore, though one species is orthorhombic, the others monoclinic, they here also correspond closely, since the axial angle β in the latter cases does not sensibly differ from 90°.

In composition, as shown by Penfield and Howe (also Sjögren), the last three species are basic orthosilicates in each of which the univalent group (MgF) or (MgOH) enters, while the Mg atoms present are in the ratio of 3 : 5 : 7. The composition given for Prolectite is theoretical only, being that which would be expected from its crystallization. In physical characters these species are very similar, and several of them may occur together at the same locality and even intercrystallized in parallel lamellæ.

The species of the group approximate closely in angle to chrysolite and chrysoberyl. The axial ratios may be compared as follows:

Prolectite........................	$\grave{a} : \bar{b} : \frac{1}{3}\dot{c}$	= 1·0803 : 1 : 0·6287
Chondrodite........................	$\grave{a} : \bar{b} : \frac{1}{5}c$	= 1·0863 : 1 . 0·6289
Humite........................	$\bar{b} : \breve{a} : \frac{1}{7}\dot{c}$	= 1·0802 : 1 : 0·6291
Clinohumite........................	$\grave{a} : \bar{b} : \frac{1}{9}c$	= 1·0803 : 1 : 0·6288
Chrysolite........................	$\bar{b} : 2\breve{a} : \dot{c}$	= 1·0735 : 1 : 0·6296
Chrysoberyl........................	$\bar{b} : 2\breve{a} : \dot{c}$	= 1·0637 : 1 : 0·6170

CHONDRODITE—HUMITE—CLINOHUMITE.

Axial ratios as given above. Habit varied, Figs. 858 to 866. Twins common, the twinning planes inclined 60°, also 30°, to c in the brachydome or clinodome zone, hence the axes crossing at angles near 60°; often repeated as trillings and as polysynthetic lamellæ (cf. Fig. 556, p. 226). Also twins, with c (001) as tw. plane. Two of the three species are often twinned together.

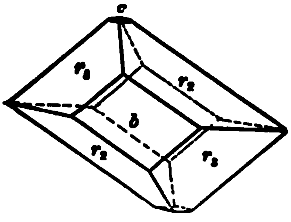
Cleavage: c sometimes distinct. Fracture subconchoidal to uneven. Brittle. H. = 6–6·5. G. = 3·1–3·2. Luster vitreous to resinous. Color white, light yellow, honey-yellow to chestnut-brown and garnet- or hyacinth-red. Pleochroism sometimes distinct. Optically +.

Chondrodite. Absorption $\mathfrak{a} > \mathfrak{c} > \mathfrak{b}$. Optically +. Ax. pl. and $Bx_a \perp b$. $Bx_o \wedge \dot{c} = \mathfrak{a} \wedge \dot{c} = +25° 52'$ Brewster; 28° 56′ Kafveltorp; 30° approx., Mte. Somma. $\beta = 1·619$; $\gamma - \alpha = 0·032$. $2H_{a.r} = 86°$ to 89°.

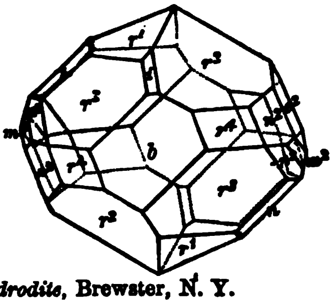
Humite. Ax. pl. $\parallel c$. $Bx \perp a$. $\gamma - \alpha = 0·035$.

Clinohumite. Ax. pl. and $Bx_a \perp b$. $Bx_o \wedge \dot{c} = \mathfrak{a} \wedge \dot{c} = +11°–12°$; 7½° approx., Brewster. $2H_{a.r} = 85°$.

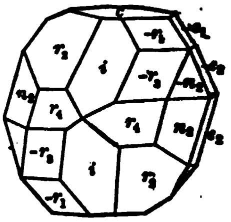
858.



859.

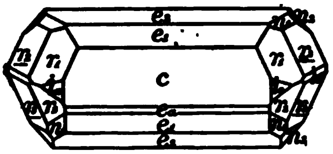


860.

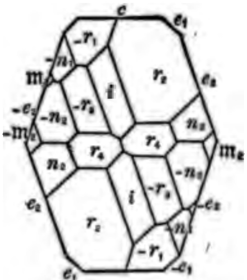


Figs. 858, 859, *Chondrodite*, Brewster, N. Y. *Chondrodite*, Sweden.
i (012), e_1 (103), e_2 (101), r_1 ($\bar{1}$27), r_3 ($\bar{1}$23), r_2 (125), r_4 (121), n_2 (111).

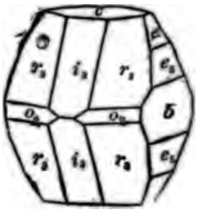
861.



862.

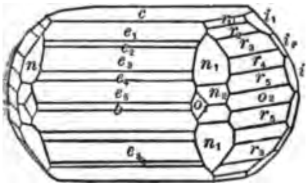


863.

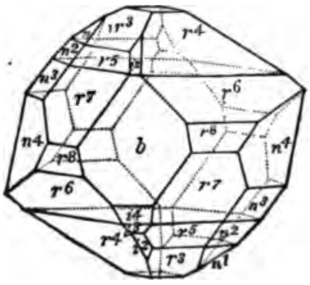


Figs. 861, 862, *Chondrodite*, Mte. Somma. *Humite*, Sweden.
Symbols see above. o_3 (210), e_1 (015), e_3 (013).

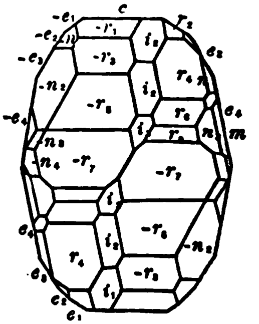
864.



865.



866.



Humite, Vesuvius. *Clinohumite*, Brewster. *Clinohumite*, Mte. Somma.
e_5 (011), r_1 (2·1·10), r_3 (216), i_2 (014), i_3 (012), e_3 (103), e_4 (101), r_5 ($\bar{1}$27), r_7 ($\bar{1}$23),
r_5 (212), n_1 (113), n_2 (111). r_6 (125), r_8 (121).

Comp.—Basic fluosilicates of magnesium with related formulas as shown in the table above. Hydroxyl replaces part of the fluorine, and iron often takes the place of magnesium.

Analyses by Penfield:

		SiO_2	MgO	FeO	F	H_2O
Chondrodite,	Brewster	33·67	54·79	5·94	5·30	2·55 = 102·25
"	Mte. Somma	33·87	56·46	3·66	5·15	2·82 = 101·96
Humite,	"	36·63	56·45	2·35	3·08	2·45 = 100·96
Clinohumite,	"	38·03	54·00	4·83	2·06	1·94 = 100·86

Pyr., etc.—B.B. infusible; some varieties blacken and then burn white. Fused with potassium bisulphate in the closed tube gives a reaction for fluorine. With the fluxes a reaction for iron. Gelatinizes with acids. Heated with sulphuric acid gives off silicon fluoride.

Obs.—Chondrodite, humite, and clinohumite all occur at Vesuvius in the ejected masses both of limestone or feldspathic type found on Monte Somma. They are associated with chrysolite, biotite, pyroxene, magnetite, spinel, vesuvianite, calcite, etc.; also less often with sanidine, meionite, nephelite. Of the three species, humite is the rarest and clinohumite of most frequent occurrence. They seldom all occur together in the same mass, and only rarely two of the species (as humite and clinohumite) appear together. Occasionally clinohumite interpenetrates crystals of humite, and parallel intergrowths with chrysolite have also been observed.

Chondrodite occurs at Mte. Somma, as above noted; at Pargas, Finland. honey-yellow in limestone; at Kafveltorp, Nya-Kopparberg, Sweden, associated with chalcopyrite, galena, sphalerite. At Brewster, N. Y., at the Tilly Foster magnetic iron mine in deep garnet-red crystals. Also probably at numerous points where the occurrence of "chondrodite" has been reported.

Humite also occurs at the Ladu mine near Filipstadt, Sweden, with magnetite in crystalline limestone. In crystalline limestone with clinohumite in Andalusia. Also in large, coarse, partly altered crystals at the Tilly Foster iron-mine at Brewster, N. Y.

Clinohumite occurs at Mte. Somma and in Andalusia; in crystalline limestone near L. Baikal in East Siberia; at Brewster, N. Y., in rare but highly modified crystals.

Prolectite is from the Ko mine, Nordmark, Sweden; very rare; imperfectly known.

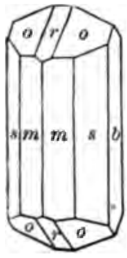
Numerous other localities of "chondrodite" have been noted, chiefly in crystalline limestone; most of them are probably to be referred to the species chondrodite, but the identity in many cases is yet to be proved. At Brewster large quantities of massive "chondrodite" occur associated with magnetite, enstatite, ripidolite, and from its extensive alteration serpentine has been formed on a large scale. The granular mineral is common in limestone in Sussex Co., N. J., and Orange Co., N. Y., associated with spinel, and occasionally with pyroxene and corundum. Also in *Mass.*, at Chelmsford, with scapolite; at South Lee, in limestone. In *Canada*, in limestone at St. Jerome, Grenville, etc., abundant.

The name chondrodite is from *χόνδρος, a grain*, alluding to the granular structure. Humite is from Sir Abraham Hume.

ILVAITE. Lievrite. Yenite.

Orthorhombic. Axes $\breve{a}:\bar{b}:\acute{c} = 0{\cdot}6665:1:0{\cdot}4427$.

867.



mm''', $110 \wedge 1\bar{1}0 = 67° 22'$. *rr'*, $101 \wedge \bar{1}01 = 67° 11'$.
ss', $120 \wedge \bar{1}20 = 73° 45'$. *oo'*, $111 \wedge \bar{1}11 = 62° 33'$.

Commonly in prisms, with prismatic faces vertically striated. Columnar or compact massive.

Cleavage: *b*, *c* rather distinct. Fracture uneven. Brittle. H. = 5·5–6. G. = 3·99–4·05. Luster submetallic. Color iron-black or dark grayish black. Streak black, inclining to green or brown. Opaque.

Comp.—$CaFe_2(FeOH)(SiO_4)_2$ or $H_2O.CaO.4FeO.Fe_2O_3.4SiO_2$ = Silica 29·3, iron sesquioxide 19·6, iron protoxide 35·2, lime 13·7, water 2·2 = 100. Manganese may replace part of the ferrous iron.

Pyr., etc.—B.B. fuses quietly at 2·5 to a black magnetic bead. With the fluxes reacts for iron. Some varieties give also a reaction for manganese. Gelatinizes with hydrochloric acid.

Obs.—Found on Elba in dolomite; on Mt. Mulatto near Predazzo, Tyrol, in granite; Schneeberg, Saxony; Fossum, in Norway. Reported as formerly found at Cumberland, R. I.; also at Milk Row quarry, Somerville, Mass. Named *Ilvaite* from the Latin name of the island (Elba).

Ardennite. Dewalquite. A vanadio-silicate of aluminium and manganese; also containing arsenic. In prismatic crystals resembling ilvaite. H. = 6–7. G. = 3·620. Yellow to yellowish brown. Found at Salm Château in the Ardennes, Belgium.

Långbanite. Manganese silicate with ferrous antimonate; formula doubtful. In iron-black hexagonal prismatic crystals. H. = 6·5. G. = 4·918. Luster metallic. From Långban, Sweden.

The following are rare lead silicates. See also p. 408.

Kentrolite. Probably $3PbO.2Mn_2O_3.3SiO_2$. In minute prismatic crystals; often in sheaf-like forms; also massive. H. = 5. G. = 6·19. Color dark reddish brown; black on the surface. From southern Chili; Långban, Sweden.

Melanotekite. $3PbO.2Fe_2O_3.3SiO_2$ or $(Fe_4O_3)Pb_3(SiO_4)_3$ Warren. Orthorhombic; prismatic. Massive; cleavable. H. = 6·5. G. = 5·73. Luster metallic to greasy. Color black to blackish gray. Occurs with native lead at Långban, Sweden. Also in crystals resembling kentrolite at Hillsboro, New Mexico.

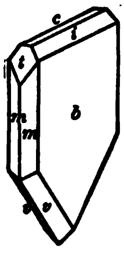
Bertrandite. $H_2Be_4Si_2O_9$ or $H_2O.4BeO.2SiO_2$. Orthorhombic-hemimorphic. In small tabular or prismatic crystals. H. = 6–7. G. = 2·59–2·60. Colorless to pale yellow. Usually occurs in feldspathic veins, often with other beryllium minerals as a result of the alteration of beryl. At the quarries of Barbin near Nantes, France; Pisek, Bohemia; Mt. Antero, Chaffee Co., Colo., with phenacite; Stoneham, Me.; Amelia Court-House, Va.

CALAMINE. Smithsonite. Hemimorphite. Kieselzinkerz, Galmei *pt. Germ.*

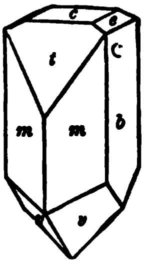
Orthorhombic-hemimorphic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·7834 : 1 : 0·4778.

mm''', 110 ∧ $1\bar{1}0$ = 76° 9'.
ss', 101 ∧ $\bar{1}01$ = 62° 46'.
tt', 301 ∧ $\bar{3}01$ = 122° 41'.
ee', 011 ∧ $0\bar{1}1$ = 51° 5'.
ii', 031 ∧ $0\bar{3}1$ = 110° 12'.
vv''' 121 ∧ $1\bar{2}1$ = 78° 26'.

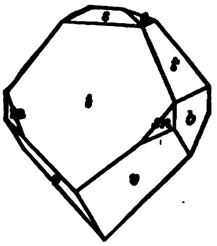
868.



869.



870.



Crystals often tabular ‖ *b*; also prismatic; faces *b* vertically striated. Usually implanted and showing one extremity only. Often grouped in sheaf-like forms and forming drusy surfaces in cavities. Also stalactitic, mammillary, botryoidal, and fibrous forms; massive and granular.

Cleavage: *m* perfect; *s* (101) less so; *c* in traces. Fracture uneven to subconchoidal. Brittle. H. = 4·5–5, the latter when crystallized. G. = 3·40–3·50. Luster vitreous; *c* subpearly, sometimes adamantine. Color white; sometimes with a delicate bluish or greenish shade; also yellowish to brown. Streak white. Transparent to translucent. Strongly pyroelectric.

Comp.—H_2ZnSiO_5 or $(ZnOH)_2SiO_3$ or $H_2O.2ZnO.SiO_2$ = Silica 25·0, zinc oxide 67·5, water 7·5 = 100. The water goes off only at a red heat; unchanged at 340° C.

Pyr., etc.—In the closed tube decrepitates, whitens, and gives off water. B.B. almost infusible (F. = 6). On charcoal with soda gives a coating which is yellow while hot, and white on cooling. Moistened with cobalt solution, and heated in O.F., this coating assumes a bright green color, but the ignited mineral itself becomes blue. Gelatinizes with acids even when previously ignited.

Diff.—Characterized by its infusibility; reaction for zinc; gelatinization with acids. Resembles some smithsonite (which effervesces with acid), also prehnite.

Obs.—Calamine and smithsonite are usually found associated in veins or beds in stratified calcareous rocks accompanying sulphides of zinc, iron and lead. Thus at Aix-la-Chapelle; Raibel and Bleiberg, in Carinthia; Moresnet in Belgium; Rezbánya, Schemnitz. At Roughten Gill, in Cumberland; at Alston Moor, white; near Matlock, in Derbyshire; Leadhills, Scotland: at Nerchinsk, in eastern Siberia.

In the United States occurs at Sterling Hill, near Ogdensburg, N. J., in fine clear crystalline masses. In Pennsylvania, at the Perkiomen and Phenixville lead mines; at

Friedensville. Abundant in Virginia, at Austin's mines in Wythe Co. With the zinc deposits of southwestern Missouri, especially about Granby, both as crystallized and massive calamine. At the Emma mine, Cottonwood Cañon, Utah.

The name *Calamine* (with *Galmei* of the Germans) is commonly supposed to be a corruption of *Cadmia*. Agricola says it is from *calamus*, a *reed*, in allusion to the slender forms (stalactitic) common in the *cadmia fornacum*.

Clinohedrite. $H_2CaZnSiO_5$. Monoclinic-clinohedral (see Figs. 331, 331*a*, p. 104). H. = 5·5. G. = 3·33. Colorless or white to amethystine. From Franklin Furnace, N. J.

Carpholite. $H_4MnAl_2Si_2O_{10}$. In radiated and stellated tufts. G. = 2·935. Color straw- to wax-yellow. Occurs at the tin mines of Schlackenwald; Wippra, in the Harz, on quartz, etc.

Lawsonite. $H_4CaAl_2Si_2O_{10}$. In prismatic orthorhombic crystals; $mm''' = 67° 16'$. G. = 3·09. Luster vitreous to greasy. Colorless, pale blue to grayish blue. Occurs in crystalline schists of the Tiburn peninsula, Marin Co., California; also in the schists of Pontgibaud and New Caledonia.

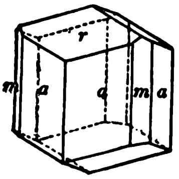
Cerite. A silicate of the cerium metals chiefly, with water. Crystals rare; commonly massive; granular. H. = 5·5. G. = 4·86. Color between clove-brown and cherry-red to gray. Occurs at Bastnäs, near Riddarhyttan, Sweden.

TOURMALINE. Turmalin *Germ.*

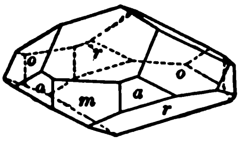
Rhombohedral-hemimorphic. Axis $\dot{c} = 0·4477$.

cr, $0001 \wedge 10\bar{1}1 = 27° 20'$. rr', $10\bar{1}1 \wedge \bar{1}101 = 46° 52'$. uu', $32\bar{5}1 \wedge \bar{3}5\bar{2}1 = 66° 1'$.
co, $0001 \wedge 02\bar{2}1 = 45° 57'$. oo', $02\bar{2}1 \wedge \bar{2}021 = 77° 0'$. uu^{v}, $32\bar{5}1 \wedge 5\bar{2}\bar{3}1 = 42° 36'$.

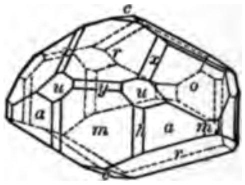
871.



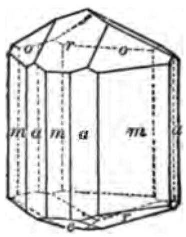
872.



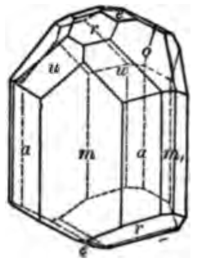
873.



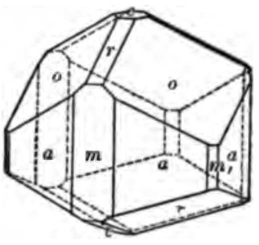
874.



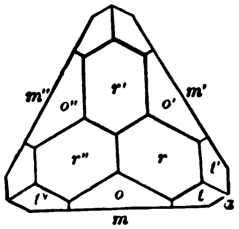
875.



876.



877.



Crystals usually prismatic in habit, often slender to acicular; rarely flattened, the prism nearly wanting. Prismatic faces strongly striated vertically, and the crystals hence often much rounded to barrel-shaped. The cross-section of the prism three-sided (*m*, Fig. 877), six-sided (*a*), or nine-sided (*m* and *a*). Crystals commonly hemimorphic. Sometimes isolated, but more commonly in parallel or radiating groups. Sometimes massive compact; also columnar, coarse or fine, parallel or divergent.

Cleavage: *a*, *r* difficult. Fracture subconchoidal to uneven. Brittle and often rather friable. H. = 7–7·5. G. = 2·98–3·20. Luster vitreous to resinous. Color black, brownish black, bluish black, most common; blue, green, red, and sometimes of rich shades; rarely white or colorless; some specimens red internally and green externally; and others red at one extremity, and green, blue or black at the other. Streak uncolored. Transparent to opaque.

Strongly dichroic, especially in deep-colored varieties; axial colors varying widely. Absorption for ω (vibrations $\perp \dot{c}$) much stronger than for ϵ (vibrations $\parallel \dot{c}$); thus sections $\parallel \dot{c}$ transmit sensibly the extraordinary ray only, and hence their use (*e.g.*, in the tourmaline tongs (p. 181)) for giving polarized light. Exhibits idiophanous figures (p. 219). Optically —. Birefringence rather high, $\omega - \epsilon = 0{\cdot}02$. Indices: $\omega_y = 1{\cdot}6366$, $\epsilon_y = 1{\cdot}6193$ colorless var.; $\omega_r = 1{\cdot}6435$, $\epsilon_r = 1{\cdot}6222$ bl. green. Sometimes abnormally biaxial. Becomes electric by friction; also strongly pyroelectric.

Var.—*Ordinary*. In crystals as above described; black much the most common. (*a*) *Rubellite;* the red, sometimes transparent; the Siberian is mostly violet-red (*siberite*), the Brazilian rose-red; that of Chesterfield and Goshen, Mass., pale rose-red and opaque; that of Paris, Me., fine ruby-red and transparent. (*b*) *Indicolite*, or *indigolite;* the blue either pale or bluish black; named from the indigo-blue color. (*c*) *Brazilian Sapphire* (in jewelry); Berlin-blue and transparent. (*d*) *Brazilian Emerald*, *Chrysolite* (or *Peridot*) *of Brazil;* green and transparent. (*e*) *Peridot of Ceylon;* honey-yellow. (*f*) *Achroite;* colorless tourmaline, from Elba. (*g*) *Aphrizite;* black tourmaline, from Krngerö, Norway. (*h*) *Columnar* and *black;* coarse columnar. Resembles somewhat common hornblende, but has a more resinous fracture, and is without distinct cleavage or anything like a fibrous appearance in the texture; it often has the appearance on a broken surface of some kinds of soft coal.

Comp.—A complex silicate of boron and aluminium, with also either magnesium, iron or the alkali metals prominent. The oxygen ratio of Si : R is in general 2 : 3 and the formula may hence be written: $\overset{I}{R}_6SiO_5 = \overset{II}{R}_3SiO_5 = \overset{III}{R}_2SiO_5$. Here $\overset{I}{R}$ = Na,Li,K; $\overset{II}{R}$ = Mg,Fe,Ca; $\overset{III}{R}$ = Al,B,Cr,Fe.

The varieties based upon composition fall into three prominent groups, between which there are many gradations:

1. ALKALI TOURMALINE. Contains sodium or lithium, or both; also potassium. G. = 3·0–3·1. Color red to green; also colorless.

2. IRON TOURMALINE. G. = 3·1–3·2. Color usually deep black.

3. MAGNESIUM TOURMALINE. G. = 3·0–3·09. Usually yellow-brown to brownish black; also colorless (anal. 54).

A *chromium tourmaline* also occurs. G. = 3·120. Color dark green.

The following are typical analyses (Riggs) of the three varieties:

	SiO_2	TiO_2	B_2O_3	Al_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	Li_2O	H_2O	F	
1. Rumford, Me., *rose*:	38·07	—	9·99	42·24	0·26	0·35	0·56	0·07	2·18	0·44	1·59	4·26	0·28	= 100·29
2. Auburn, *black*:	34·99	—	9·63	33·96	14·23	0·06	0·15	1·01	2·01	0·34	*tr.*	3·62	—	= 100·00
3. Gouverneur, *brown*:	37·39	1·19	10·73	27·89[a]	0·64	—	2·78	14·09	1·72	0·16	*tr.*	3·83	*tr.?*	= 100·42

[a] Including 0·10 Fe_2O_3.

Pyr., etc.—The magnesia varieties fuse rather easily to a white blebby glass or slag; the iron-magnesia var. fuse with a strong heat to a blebby slag or enamel; the iron var. fuse with difficulty, or, in some, only on the edges; the iron-magnesia-lithia var. fuse on the edges, and often with great difficulty, and some are infusible; the lithia var. are infusible. With the fluxes many varieties give reactions for iron and manganese. Fused with a mixture of potassium bisulphate and fluor-spar gives a distinct reaction for boric acid. Not decomposed by acids.

Diff.—Characterized by its crystallization, prismatic forms usual, which are three-, six-, or nine-sided, and often with rhombohedral terminations; massive forms with columnar structure; also by absence of cleavage (unlike amphibole and epidote); in the common black kinds by the coal-like fracture; by hardness; by difficult fusibility (common kinds), compared with garnet and vesuvianite. The boron test is conclusive.

Readily distinguished in thin sections by its somewhat high relief; rather strong interference-colors; negative uniaxial character; decided colors in ordinary light in which basal sections often exhibit a zonal structure. Also, especially, by its remarkable absorption when the direction of crystal elongation is ⊥ to the vibration-plane of the lower nicol: this with its lack of cleavage distinguishes it from biotite and amphibole, which alone among rock-making minerals show similar strong absorption.

Obs.—Commonly found in granite and gneisses as a result of fumarole action or of mineralizing gases in the fluid magma, especially in the pegmatite veins associated with such rocks; at the periphery of such masses or in the schists, or altered limestones, gneisses, etc., immediately adjoining them. It marks especially the boundaries of granitic masses, and its associate minerals as those characteristic of such occurrences: quartz, albite, microcline, muscovite, etc. The variety in granular limestone or dolomite is commonly brown; the bluish-black var. sometimes associated with tin ores; the brown with titanium; the lithium variety is often associated with lepidolite. Red or green varieties, or both, occur near Ekaterinburg in the Ural; Elba; Campolongo in Tessin, Switzerland; Penig, Saxony; also the province Minas Geraes, Brazil; yellow and brown from Ceylon; dark brown varieties from Eibenstock, Saxony; the Zillerthal; black from Arendal, Norway; Snarum; Kragerö; pale yellowish brown at Windisch Kappel in Carinthia; fine black crystals occur in Cornwall at different localities.

In the U. States, in *Maine* at Paris and Hebron, magnificent red and green tourmalines with lepidolite, etc.; also blue and pink varieties; and at Norway; pink at Rumford, embedded in lepidolite; at Auburn in clear crystals of a delicate pink or lilac with lepidolite, etc.; at Albany, green and black. In *Mass.*, at Chesterfield, red, green, and blue; at Goshen, blue and green; at Norwich, New Braintree, and Carlisle, good black crystals. In *N. Hamp.*, Grafton, Acworth; at Orford, brownish black in steatite. In *Conn.*, at Monroe, dark brown in mica-slate; at Haddam, black in mica slate; also fine pink and green; at New Milford, black. In *N. York*, near Gouverneur, brown crystals, with tremolite, etc., in granular limestone; black near Port Henry, Essex Co.; near Edenville; splendid black crystals at Pierrepont, St. Lawrence Co.; colorless and glassy at De Kalb; dark brown at McComb. In *N. Jersey*, at Hamburg and Newton, black and brown crystals in limestone, with spinel; also grass-green crystals in crystalline limestone near Franklin Furnace. In *Penn.*, at Newlin, Chester Co.; near Unionville, yellow; at Chester, fine black; Middletown, black; Marple, green in talc; near New Hope on the Delaware, large black crystals. A chrome var. from the chromite beds in Montgomery Co., *Maryland*. In *N. Car.*, Alexander Co., in fine black crystals with emerald and hiddenite. In *California*, fine groups of rubellite in lepidolite in San Diego Co.

In *Canada*, in the province of Quebec, yellow crystals in limestone at Calumet Falls, Litchfield, Pontiac Co.; at Hunterstown; fine brown crystals at Clarendon, Pontiac Co.; black at Grenville and Argenteuil, Argenteuil Co. In Ontario, in fine crystals at N. Burgess, Lanark Co.; Galway and Stoney L. in Dummer, Peterborough Co.

The name *turmalin* from *Turamali* in Cingalese (applied to zircon by jewelers of Ceylon) was introduced into Holland in 1703, with a lot of gems from Ceylon.

Dumortierite. A basic aluminium silicate, perhaps $4Al_2O_3.3SiO_2$.

Orthorhombic. Prismatic angle approximately 60°. Usually in fibrous to columnar aggregates. Cleavage: *a* distinct; also prismatic, imperfect. H. = 7. G. = 3·26–3·36. Luster vitreous. Color bright smalt-blue to greenish blue. Transparent to translucent. Pleochroism very strong: $\mathfrak{c}$ colorless, $\mathfrak{b}$ reddish violet, $\mathfrak{a}$ deep ultramarine-blue. Exhibits idiophanous figures, analogous to andalusite. Optically −. Ax. pl. ∥ *b*. Bx ⊥ *c*. $\gamma - \alpha = 0·010$.

Recognized in thin section by its rather high relief; low interference-colors (like those of quartz); occurrence in slender prisms, needles or fibers, with negative optical extension; parallel extinction; biaxial character and especially by its remarkable pleochroism.

Found embedded in feldspar in blocks of gneiss at Chaponost, near Lyons, France; from Wolfshau, near Schmiedeberg, Silesia; in the iolite of the gneiss of Tvedestrand, Norway. In the U. S., it occurs near Harlem, New York Island, in the pegmatoid portion of a biotite-gneiss; in a quartzose rock at Clip, Yuma Co., Arizona.

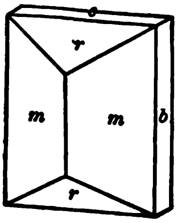
STAUROLITE. Staurotide.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·4734 : 1 : 0·6828$.

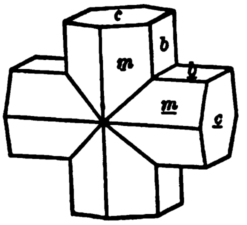
mm''', $110 \wedge 1\bar{1}0 = 50° 40'$. cr, $001 \wedge 101 = 55° 16'$.
rr', $101 \wedge \bar{1}01 = 110° 32'$. mr, $110 \wedge 101 = 42° 2'$.

Twins cruciform: tw. pl. *x* (032), the crystals crossing nearly at right angles; tw. pl. *z* (232), crossing at an angle of 60° approximately; tw. pl. *y* (230) rare, also in repeated twins (cf. Figs. 359, p. 122, 409, p. 128, 411, p. 129). Crystals commonly prismatic and flattened ‖ $\bar{b}$; often with rough surfaces.

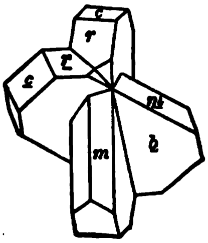
878.



879.



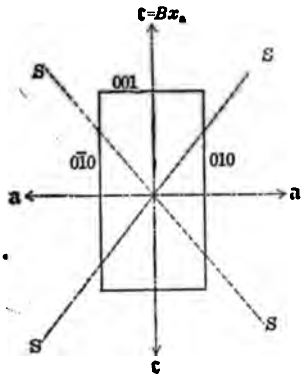
880.



Cleavage: *b* distinct, but interrupted; *m* in traces. Fracture subconchoidal. Brittle. H. = 7–7·5. G. = 3·65–3·77. Subvitreous, inclining to resinous. Color dark reddish brown to brownish black, and yellowish brown. Streak uncolored to grayish. Translucent to nearly or quite opaque. Pleochroism distinct: c (= $\dot{c}$) hyacinth-red to blood-red, a, b yellowish red; or c gold-yellow, a, b light yellow to colorless. Optically +. Ax. pl. ‖ *a*. Bx ⊥ *c*. $2H_{a.r} = 113° 10'$. $\beta = 1·75$, $\gamma - \alpha = 0·012$.

Comp.—$HFeAl_5Si_2O_{13}$, which may be written $(AlO)_4(AlOH)Fe(SiO_4)_2$ or $H_2O.2FeO.5Al_2O_3.4SiO_2$ = Silica 26·3, alumina 55·9, iron protoxide 15·8, water 2·0 = 100 Penfield. Magnesium (also manganese) replaces a little of the ferrous iron; ferric iron part of the aluminium.

881.



Nordmarkite from Nordmark, Sweden, contains manganese in large amounts.

Pyr., etc.—B.B. infusible, excepting the manganesian variety, which fuses easily to a black magnetic glass. With the fluxes gives reactions for iron, and sometimes for manganese. Imperfectly decomposed by sulphuric acid.

Diff.—Characterized by the obtuse prism (unlike andalusite, which is nearly square); by the frequency of twinning forms; by hardness and infusibility.

Under the microscope, sections show a decided color (yellow to red or brown) and strong pleochroism (yellow and red); also characterized by strong refraction (high relief), rather bright interference-colors, parallel extinction and biaxial character (generally positive in the direction of elongation). Easily distinguished from rutile (p. 345) by its biaxial character and lower interference-colors.

Obs.—Usually found in crystalline schists, as mica schist, argillaceous schist, and gneiss, as a result of regional or contact metamorphism; often associated with garnet, sillimanite, cyanite, and tourmaline. Sometimes encloses symmetrically arranged carbonaceous impurities like andalusite (p. 438). Other impurities are also often present, especially silica, sometimes up to 30 to 40 p. c.; also garnet, mica, and perhaps magnetite, brookite.

Occurs with cyanite in paragonite schist, at Mt. Campione, Switzerland; in the Zillerthal, Tyrol; Goldenstein in Moravia; Aschaffenburg, Bavaria; in large twin crystals in the mica schists of Brittany and Scotland. In the province of Minas Geraes, Brazil.

Abundant throughout the mica schists of New England. In *Maine*, at Windham. In *N. Hamp.*, brown at Franconia; at Lisbon; on the shores of Mink Pond, loose in the soil. In *Mass.*, at Chesterfield, in fine crystals. In *Conn.*, at Bolton, Vernon, etc.; Southbury with garnets; at Litchfield, black crystals. In *N. Carolina*, near Franklin, Macon Co.; also in Madison and Clay counties. In *Georgia*, in Fannin Co., loose in the soil in fine crystals.

Named from σταυρός, *a cross*.

Kornerupine. $MgAl_2SiO_6$. In fibrous to columnar aggregates, resembling sillimanite. H. = 6·5. G. = 3·273 kornerupine; 3·341 prismatine. Colorless to white, or brown.

Kornerupine occurs at Fiskernäs on the west coast of Greenland. *Prismatine* is from Waldheim, Saxony.

Sapphirine. $Mg_5Al_{12}Si_2O_{27}$. In indistinct tabular crystals. Usually in disseminated grains, or aggregations of grains. H. = 7·5. G. = 3·42–3·48. Color pale blue or green. From Fiskernäs, southwestern Greenland.

SILICATES.

Section B. Chiefly Hydrous Species.

The SILICATES of this second section include the true hydrous compounds, that is, those which contain water of crystallization, like the zeolites; also the hydrous amorphous species, as the clays, etc. There are also included certain species—as the Micas, Talc, Kaolinite—which, while they yield water upon ignition, are without doubt to be taken as acid or basic metasilicates, orthosilicates, etc. Their relation, however, is so close to other true hydrous species that it appears more natural to include them here than to have placed them in the preceding chapter with other acid and basic salts. Finally, some species are referred here about whose chemical constitution and the part played by the water present there is still much doubt. The divisions recognized are as follows:

I. Zeolite Division.

1. Introductory Subdivision. 2. Zeolites.

II. Mica Division.

1. Mica Group. 2. Clintonite Group. 3. Chlorite Group.

III. Serpentine and Talc Division.

Chiefly Silicates of Magnesium.

IV. Kaolin Division.

Chiefly Silicates of Aluminium; for the most part belonging to the group of the clays.

V. Concluding Division.

Species not included in the preceding divisions; chiefly silicates of the heavy metals, iron, manganese, etc.

I. Zeolite Division.

1. Introductory Subdivision.

Of the species here included, several, as Apophyllite, Okenite, etc., while not strictly ZEOLITES, are closely related to them in composition and method of occurrence. Pectolite (p. 395) and Prehnite (p. 442) are also sometimes classed here.

Inesite. $2(Mn,Ca)SiO_3 + H_2O$. Crystals small, prismatic; also fibrous, radiated and spherulitic. H. = 6. G. = 3·029. Color rose- to flesh-red. Occurs at the manganese mines near Dillenburg, Germany. *Rhodotilite* is the same species from the Harstig mine, Pajsberg, Sweden.

Ganophyllite. $6H_2O.7MnO.Al_2O_3.8SiO_2$. In short prismatic crystals; also foliated, micaceous. Color brown. H. = 4–4·5. G. = 2·84. From the Harstig mine, near Pajsberg, Sweden.

Okenite. $H_2CaSi_2O_6 + H_2O$. Commonly fibrous; also compact. H. = 4·5–5. G. = 2·28–2·36. Color white, with a shade of yellow or blue. Occurs in basalt or related eruptive rocks; as in the Färöer; Iceland; Disko, Greenland; Poona, India, etc.

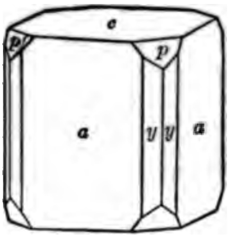
Gyrolite. $H_2Ca_2Si_3O_9 + H_2O$. In white concretions, lamellar-radiate in structure. From the Isle of Skye, with stilbite, laumontite, etc.; in India, etc. With apophyllite of New Almaden, California; also N. Scotia.

APOPHYLLITE.

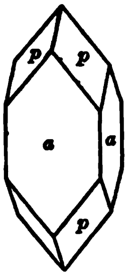
Tetragonal. Axis $\dot{c} = 1·2515$.

ay, 100 ∧ 310 = 18° 26′.
cp, 001 ∧ 111 = 60° 32′.
ap, 100 ∧ 111 = 52° 0′.
pp′, 111 ∧ $\bar{1}$11 = 76° 0′.

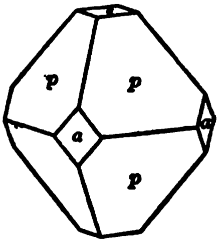
882.



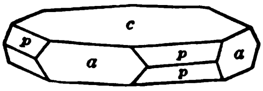
883.



884.



885.



Habit varied; in square prisms (*a*) usually short and terminated by *c* or by *cp*, and then resembling a cube or cubo-octahedron; also acute pyramidal (*p*) with or without *c* and *a*; less often thin tabular ∥ *c*. Faces *c* often rough; *a* bright but vertically striated; *p* more or less uneven. Also massive and lamellar; rarely concentric radiated.

Cleavage: *c* highly perfect; *m* less so. Fracture uneven. Brittle. H. = 4·5–5. G. = 2·3–2·4. Luster of *c* pearly; of other faces vitreous. Color white, or grayish; occasionally with a greenish, yellowish, or rose-red tint, flesh-red. Transparent; rarely nearly opaque. Birefringence low; usually +, also −. Often shows anomalous optical characters (Art. **411**, Fig. 565). Indices: $\omega_r = 1·5309$ Li, $\epsilon_r = 1·5332$.

Comp.—$H_7KCa_4(SiO_3)_8 + 4\frac{1}{2}H_2O$ or $K_2O.8CaO.16SiO_2.16H_2O$ = Silica 53·7, lime 25·0, potash 5·2, water 16·1 = 100. A small amount of fluorine replaces part of the oxygen.

The above formula differs but little from $H_2CaSi_2O_6 + H_2O$, in which potassium replaces part of the basic hydrogen. The form often accepted, $H_2(Ca,K)Si_2O_6 + H_2O$, corresponds less well with the analyses.

Pyr., etc.—In the closed tube exfoliates, whitens, and yields water, which reacts acid. In the open tube, when fused with salt of phosphorus, gives a fluorine reaction. B.B.

exfoliates, colors the flame violet (potash), and fuses to a white vesicular enamel. F. = 1·5. Decomposed by hydrochloric acid, with separation of slimy silica.

Diff.—Characterized by its tetragonal form, the square prism and pyramid the common habits; by the perfect basal cleavage and pearly luster on this surface.

Obs.—Occurs commonly as a secondary mineral in basalt and related rocks, with various zeolites, also datolite, pectolite, calcite; also occasionally in cavities in granite, gneiss, etc. Greenland, Iceland, the Färöer, and British India afford fine specimens of apophyllite in amygdaloidal basalt or diabase. Occurs also at Andreasberg, of a delicate pink; Radauthal in the Harz; at Orawitza, Hungary, with wollastonite; Utö, Sweden; on the Seisser Alp in Tyrol; Guanajuato, Mexico, often of a beautiful pink upon amethyst.

In the U. S., large crystals occur at Bergen Hill, N. J.; in Penn., at the French Creek mines, Chester Co.; at the Cliff mine, Lake Superior region; Table Mt. near Golden, Colo.; in California, at the mercury mines of New Almaden often stained brown by bitumen; also from Nova Scotia at Cape Blomidon, and other points.

Named by Haüy in allusion to its tendency to exfoliate under the blowpipe, from *ἀπό* and *φύλλον*, *a leaf*. Its whitish pearly aspect, resembling the eye of a fish after boiling, gave rise to the earlier name *Ichthyophthalmite*, from *ἰχθύς*, *fish*, *ὀφθαλμός*, *eye*.

2. Zeolites.

The ZEOLITES form a family of well-defined hydrous silicates, closely related to each other in composition, in conditions of formation, and hence in method of occurrence. They are often with right spoken of as analogous to the Feldspars, like which they are all silicates of aluminium with sodium and calcium chiefly, also rarely barium and strontium; magnesium, iron, etc., are absent or present only through impurity or alteration. Further, the composition in a number of cases corresponds to that of a hydrated feldspar; while fusion and slow recrystallization result in the formation from some of them of anorthite ($CaAl_2Si_2O_8$) or a calcium-albite ($CaAl_2Si_6O_{16}$) as shown by Doelter. The Zeolites do not, however, form a single group of species related in crystallization, like the Feldspars, but include a number of independent groups widely diverse in form and distinct in composition; chief among these are the monoclinic PHILLIPSITE GROUP; the rhombohedral CHABAZITE GROUP, and the orthorhombic (and monoclinic) NATROLITE GROUP. A transition in composition between certain end compounds has been more or less well established in certain cases, but, unlike the Feldspars, with these species calcium and sodium seem to replace one another and an increase in alkali does not necessarily go with an increase in silica.

Like other hydrous silicates they are characterized by inferior hardness, chiefly from 3·5 to 5·5, and the specific gravity is also lower than with corresponding anhydrous species, chiefly 2·0 to 2·4. Corresponding to these characters, they are rather readily decomposed by acids, many of them with gelatinization. The intumescence B.B., which gives the name to the family (from *ζεῖν*, *to boil*, and *λίθος*, *stone*) is characteristic of a large part of the species.

The Zeolites are all secondary minerals, occurring most commonly in cavities and veins in basic igneous rocks, as basalt, diabase, etc.; less frequently in granite, gneiss, etc. In these cases the lime and the soda in part have been chiefly yielded by the feldspar; the soda also by elæolite, sodalite, etc.; potash by leucite, etc. The different species of the family are often associated together; also with pectolite and apophyllite (sometimes included with the zeolites), datolite, prehnite and, further, calcite.

Ptilolite. $RAl_2Si_{10}O_{24} + 5H_2O$. Here $R = Ca : K_2 : Na_2 = 6 : 2 : 1$ approx. In short capillary needles, aggregated in delicate tufts. Colorless, white. Occurs upon a bluish chalcedony in cavities in a vesicular augite-andesite found in fragments in the conglomerate beds of Green and Table mountains, Jefferson Co., Colorado.

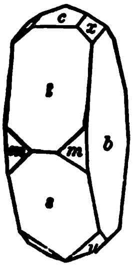
Mordenite. $3RAl_2Si_{10}O_{24} + 20H_2O$, where $R = K_2 : Na_2 : Ca = 1 : 1 : 1$. In minute crystals resembling heulandite in habit and angles; also in small hemispherical or reniform concretions with fibrous structure. H. = 3–4. G. = 2·15. Color white, yellowish or pinkish. Occurs near Morden, King's Co., Nova Scotia, in trap; also in western Wyoming near Hoodoo Mt., on the ridge forming the divide between Clark's Fork and the East Fork (Lamar R.) of the Yellowstone river.

HEULANDITE. Stilbite *some authors.*

Monoclinic. Axes: $\grave{a} : \breve{b} : \grave{c} = 0·4035 : 1 : 0·4293$; $\beta = 88° 34\frac{1}{2}'$.

886.

mm''', 110 ∧ 1$\bar{1}$0 = 48° 56'. *cs*, 001 ∧ $\bar{2}$01 = 66° 0'.
ct, 001 ∧ 201 = 63° 40'. *cx*, 001 ∧ 021 = 40° 38$\frac{1}{2}$'.



Crystals sometimes flattened ∥ *b*, the surface of pearly luster (Fig. 886; also Fig. 22, p. 11); form often suggestive of the orthorhombic system, since the angles *cs* and *ct* differ but little. Also in globular forms; granular.

Cleavage: *b* perfect. Fracture subconchoidal to uneven. Brittle. H. = 3·5–4. G. = 2·18–2·22. Luster of *b* strong pearly; of other faces vitreous. Color various shades of white, passing into red, gray and brown. Streak white. Transparent to subtranslucent. Optically +. Ax. pl. and $Bx_a \perp b$. Ax. pl. and Bx_o for some localities nearly ∥ *c*; also for others nearly ⊥ *c* in white light (Dx.). $Bx_o \wedge \grave{c} = +57\frac{1}{2}°$. Axial angle variable, from 0° to 92°; usually $2E_r = 52°$. Birefringence low. $\beta = 1·499$; $\gamma - \alpha = 0·007$.

Comp.—$H_4CaAl_2(SiO_3)_6 + 3H_2O$ or $5H_2O.CaO.Al_2O_3.6SiO_2$ = Silica 59·2, alumina 16·8, lime 9·2, water 14·8 = 100.

Strontium is usually present, sometimes up to 3·6 p. c.

Pyr.—As with stilbite, p. 457.

Obs.—Heulandite occurs principally in basaltic rocks, associated with chabazite, stilbite and other zeolites; also in gneiss, and occasionally in metalliferous veins.

The finest specimens of this species come from Berufiord, and elsewhere in Iceland; the Färöer; in British India, near Bombay; also in railroad cuttings in the Bhor and Thul Ghâts. Also occurs in the Kilpatrick Hills, near Glasgow; on the I. of Skye; Fassathal, Tyrol; Andreasberg, Harz.

In the United States, in diabase at Bergen Hill, New Jersey; on north shore of Lake Superior; with haydenite, at Jones's Falls, near Baltimore (*beaumontite*). At Peter's Point, Nova Scotia; also at Cape Blomidon, and other points.

Named after the English mineralogical collector, H. Heuland, whose cabinet was the basis of the classical work (1837) of Lévy.

Brewsterite. $H_4(Sr,Ba,Ca)Al_2Si_6O_{16} + 3H_2O$. In prismatic crystals. H = 5. G. = 2·45. Color white, inclining to yellow and gray. From Strontian in Argyleshire; the Giant's Causeway; near Freiburg in Breisgau, etc.

Epistilbite. Probably like heulandite, $H_4CaAl_2Si_6O_{18} + 3H_2O$. Crystals monoclinic, uniformly twins; habit prismatic. In radiated spherical aggregations; also granular. G. = 2·25. Color white. Occurs with scolecite at the Berufiord, Iceland; the Färöer; Poona, India; in small reddish crystals, at Margaretville, N. Scotia, etc. *Reissite* is from Santorin.

Phillipsite Group. Monoclinic.

		$\grave{a} : \breve{b} : \grave{c}$	β
Wellsite	$(Ba,Ca,K_2)Al_2Si_3O_{10} + 3H_2O$	0·768 : 1 : 1·245	53° 27'
Phillipsite	$(K_2,Ca)Al_2Si_4O_{12} + 4\frac{1}{2}H_2O$	0·7095 : 1 : 1 2563	55° 37'
Harmotome	$(K_2,Ba)Al_2Si_5O_{14} + 5H_2O$	0·7032 : 1 : 1·2310	55° 10'
Stilbite	$(Na_2,Ca)Al_2Si_6O_{16} + 6H_2O$	0·7623 : 1 : 1·1940	50° 50'

The above species, while crystallizing in the monoclinic system, are remarkable for the pseudo-symmetry exhibited by their twinned forms. Certain of these twins are pseudo-orthorhombic, others pseudo-tetragonal and more complex twins even pseudo-isometric.

Fresenius has shown that the species of this group may be regarded as forming a series, in which the ratio of RO : Al_2O_3 is constant (= 1 : 1), and that of SiO_2 : H_2O also chiefly 1 : 1. The end compounds assumed by him are:

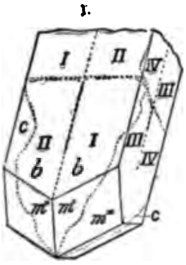
$$RAl_2Si_6O_{16} + 6H_2O; \qquad R_2Al_4Si_4O_{16} + 6H_2O.$$

Here R = Ca chiefly, in phillipsite and stilbite, Ba in harmotome, while in wellsite Ba, Ca, and K_2 are present; also in smaller amounts Na_2, K_2. The first of the above compounds may be regarded as a hydrated calcium albite, the second as a hydrated anorthite. Pratt and Foote, however, show that the anorthite end compound more probably has the formula $RAl_2Si_2O_8 + 2H_2O$ (or this doubled). The formulas given beyond are those corresponding to reliable analyses of certain typical occurrences.

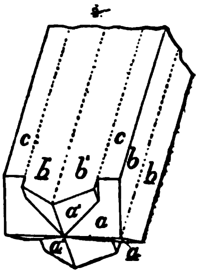
Wellsite. $RAl_2Si_3O_{10} + 3H_2O$ with R = Ca : Ba : K_2 = 3 : 1 : 3; Sr and Na also present in small amount. Percentage composition: SiO_2 42·9, Al_2O_3 24·3, BaO 6·6, CaO 7·3, K_2O 6·1, H_2O 12·8 = 100. Monoclinic (axes p. 454); in complex twins, analogous to those of phillipsite and harmotome (Figs. 887, 888). Brittle. No cleavage. H. = 4–4·5. G. = 2·278–2·366. Luster vitreous. Colorless to white. Optically +. Bx ⊥ *b* (010). Birefringence weak.

Occurs at the Buck Creek (Cullakanee) corundum mine in Clay Co., No. Carolina; in isolated crystals attached to feldspar, also to hornblende and corundum; intimately associated with chabazite.

887.



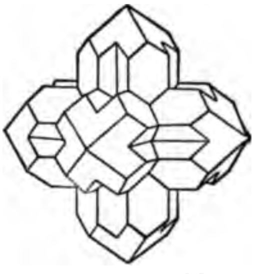
888.



PHILLIPSITE.

Monoclinic. Axes $\breve{a} : \bar{b} : \grave{c} = 0·7095 : 1 : 1·2563$; $\beta = 55° 37'$.

889.



mm''', 110 ∧ $1\bar{1}0$ = 60° 42'. *cm*, 001 ∧ 110 = 60° 50'.
af, 100 ∧ $\bar{1}01$ = 34° 23'. *ee'*, 011 ∧ $0\bar{1}1$ = 92° 4'.

Crystals uniformly penetration-twins, but often simulating orthorhombic or tetragonal forms. Twins sometimes, but rarely, simple (1) with tw. pl. *c*, and then cruciform so that diagonal parts on *b* belong together, hence a fourfold striation, ∥ edge *b*/*m*, may be often observed on *b*. (2) Double twins, the simple twins just noted united with *e* (011) as tw. pl., and, since *ee'* varies but little from 90°, the result is a nearly square prism, terminated by what appear to be pyramidal faces each with a double series of striations away from the medial line. See Figs. 422–424, p. 130; also Fig. 362, p. 122. Faces *b* often finely striated as just noted, but striations sometimes absent and in general not so distinct as with harmotome; also *m* striated ∥ edge *b*/*m*. Crystals either isolated, or grouped in tufts or spheres, radiated within and bristled with angles at surface.

Cleavage: *c*, *b*, rather distinct. Fracture uneven. Brittle. H. = 4–4·5. G. = 2·2. Luster vitreous. Color white, sometimes reddish. Streak uncolored. Translucent to opaque. Optically +. Ax. pl. and $Bx_o \perp b$. The ax. pl. lies in the obtuse angle of $\grave{a}\ \grave{c}$, and is usually inclined to $\grave{a}$ about 15° to 20°, or 75° to 70° to the normal to *c*. The position, however, is variable. $2H_{a.r} = 71°–84°$.

Comp. — In some cases the formula is $(K_2,Ca)Al_2Si_4O_{12} + 4\frac{1}{2}H_2O$ = Silica 48·8, alumina 20·7, lime 7·6, potash 6·4, water 16·5 = 100. Here Ca : K_2 = 2 : 1.

Pyr., **etc.**—B.B. crumbles and fuses at 3 to a white enamel. Gelatinizes with hydrochloric acid.

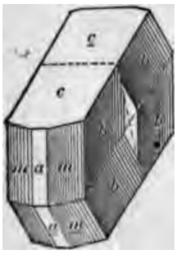
Obs.—In translucent crystals in basalt, at the Giant's Causeway, Ireland; at Capo di Bove, near Rome; Aci Castello and elsewhere in Sicily; among the lavas of Mte. Somma; at Stempel, near Marburg; Annerod, near Giessen; in the Kaiserstuhl, with faujasite; Salesl, Bohemia; in the ancient lavas of the Puy-de-Dôme.

HARMOTOME.

Monoclinic. Axes $\grave{a} : \breve{b} : \acute{c} = 0·7031 : 1 : 1·2310$; $\beta = 55° 10'$.

Crystals uniformly cruciform penetration-twins with *c* as tw. pl.; either (1) simple twins (Fig. 890) or (2) united as fourlings with tw. pl. *e*. These double twins often have the aspect of a square prism with diagonal pyramid, the latter with characteristic feather-like striations from the medial line. Also in more complex groups analogous to those of phillipsite.

890.



Cleavage: *b* easy, *c* less so. Fracture uneven to subconchoidal. Brittle. H. = 4·5. G. = 2·44–2·50. Luster vitreous. Color white; passing into gray, yellow, red or brown. Streak white. Subtransparent to translucent. Optically +. Ax. pl. and $Bx_a \perp b$. Ax. pl. in obtuse angle $\grave{a}\,\acute{c}$ and inclined about 65° to $\grave{a}$ and 60° to $\acute{c}$. $2H_{a.r} = 87° 2'$. $\beta = 1·516$.

Comp.—In part $H_2(K_2,Ba)Al_2Si_5O_{14} + 4H_2O$ or $(K_2,Ba)O.Al_2O_3.5SiO_2.5H_2O$ = Silica 47·1, alumina 16·0, baryta 20·6, potash 2·1, water 14·1 = 100.

Pyr., **etc.**—B.B. whitens, then crumbles and fuses without intumescence at 3·5 to a white translucent glass. Some varieties phosphoresce when heated. Decomposed by hydrochloric acid without gelatinizing.

Obs.—Occurs in basalt and similar eruptive rocks, also phonolite, trachyte; not infrequently on gneiss, and in some metalliferous veins. At Strontian, in Scotland; in a metalliferous vein at Andreasberg in the Harz; at Rudelstadt, Silesia; Oberstein, on agate in siliceous geodes; at Kongsberg, Norway.

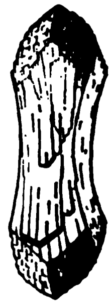
In the U. S., in small brown crystals with stilbite on the gneiss of New York island; near Pt. Arthur, L. Superior.

Named from ἁρμός, *joint*, and τέμνειν, *to cut*, alluding to the fact that the pyramid (made by the prismatic faces in twinning position) divides parallel to the plane that passes through the terminal edges.

STILBITE. Desmine.

Monoclinic. Axes: $\grave{a} : \breve{b} : \acute{c} = 0·7623 : 1 : 1·1940$; $\beta = 50° 50'$.

891.



Crystals uniformly cruciform penetration-twins with tw. pl. *c*, analogous to phillipsite and harmotome. The apparent form a rhombic pyramid whose faces are in fact formed by the planes *m* and *m*; the vertical faces being then the pinacoids *b* and *c* (cf. Figs. 560–562, p. 227). Usually thin tabular ‖ *b*. These compound crystals are often grouped in nearly parallel position, forming sheaflike aggregates with the side face (*b*), showing its characteristic pearly luster, often deeply depressed. Also divergent or radiated; sometimes globular and thin lamellar-columnar.

Cleavage: *b* perfect. Fracture uneven. Brittle. H. = 3·5–4. G. = 2·094–2·205; 2·161 Haid. Luster vitreous; of *b* pearly. Color white; occasionally yellow, brown or red, to brick-red. Streak uncolored. Transparent to translucent. Optically −. Ax. pl. ‖ *b*. Bx_a inclined 5° to axis $\grave{a}$ in obtuse angle $\grave{a}\,\acute{c}$; hence $Bx_a \wedge \acute{c} = -55° 50'$. Ax. angle approx. 52° to 53° (blue glass); $\beta = 1·498$.

Comp.—For most varieties $H_4(Na_2,Ca)Al_2Si_6O_{18} + 4H_2O$ or $(Na_2,Ca)O.Al_2O_3.6SiO_2.6H_2O$ = Silica 57·4, alumina 16·3, lime 7·7, soda 1·4, water 17·2 = 100. Here $Ca : Na_2 = 6:1$.

Some kinds show a lower percentage of silica, and these have been called *hypostilbite*.

Pyr., **etc.**—B.B. exfoliates, swells up, curves into fan-like or vermicular forms, and fuses to a white enamel. F. = 2–2·5. Decomposed by hydrochloric acid, without gelatinizing.

Diff.—Characterized by the frequency of radiating or sheaf-like forms; by the pearly luster on the clinopinacoid. Does not gelatinize with acids.

Obs.—Stilbite occurs mostly in cavities in amygdaloidal basalt, and similar rocks. It is also found in some metalliferous veins, and in granite and gneiss.

Abundant on the Färöer; in Iceland; on the Isle of Skye, in amygdaloid; also in Dumbartonshire, Scotland, in red crystals; the Giant's Causeway, Ireland; at Andreasberg in the Harz, and Kongsberg and Arendal in Norway, with iron ore; on the Seisser Alp in Tyrol, and at the Pufferloch (*pufferite*); on the granite of Striegau, Silesia. A common mineral in the Deccan trap area of British India.

In North America, sparingly in small crystals at Chester and at the Somerville syenite quarries, Mass.; at Phillipstown, N. Y.; and at Bergen Hill, New Jersey; also at the Michipicoten Islands, Lake Superior. At Partridge Island, Nova Scotia; also at Isle Haute, Digby Neck, Cape Blomidon, etc.

The name ***stilbite*** is from στίλβη, ***luster***; and ***desmine*** from δέσμη, ***a bundle***.

Gismondite. Perhaps $CaAl_2Si_4O_{12} + 4H_2O$. In pyramidal crystals, pseudo-tetragonal. H. = 4·5. G. = 2·265. Colorless or white, bluish white, grayish, reddish. Occurs in the leucitophyre of Mt. Albano, near Rome, at Capodi Bove, and elsewhere, etc.; on the Gorner glacier, near Zermatt; Schlauroth near Görlitz in Silesia; Salesl, Bohemia, etc.

LAUMONTITE. Leonhardite. Caporcianite.

Monoclinic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 1·1451 : 1 : 0·5906; β = 68° 46′.

Twins: tw. pl. *a*. Common form the prism *m* (mm''' = 93° 44′) with oblique termination *e*, $\bar{2}01$ (ce = 56° 55′). Also columnar, radiating and divergent.

Cleavage: *b* and *m* very perfect; *a* imperfect. Fracture uneven. Not very brittle. H. = 3·5–4. G. = 2·25–2·36. Luster vitreous, inclining to pearly upon the faces of cleavage. Color white, passing into yellow or gray, sometimes red. Streak uncolored. Transparent to translucent; becoming opaque and usually pulverulent on exposure. Optically —. Ax. pl. ‖ *b*. $Bx_a \wedge \dot{c} = +$ 65° to 70°. Dispersion large, $\rho < v$; inclined, slight. $2E_r$ = 52° 24′.

Comp., Var.—$H_4CaAl_2Si_4O_{14} + 2H_2O = 4H_2O.CaO.Al_2O_3.4SiO_2$ = Silica 51·1, alumina 21·7, lime 11·9, water 15·3 = 100.

Leonhardite is a laumontite which has lost part of its water (to one molecule), and the same is probably true of ***caporcianite***. ***Schneiderite*** is laumontite from the serpentine of Monte Catini, Italy, which has undergone alteration through the action of magnesian solutions.

Pyr., etc.—B.B. swells up and fuses at 2·5–3 to a white enamel. Gelatinizes with hydrochloric acid.

Obs.—Occurs in the cavities of basalt and similar eruptive rocks; also in porphyry and syenite, and occasionally in veins traversing clay slate with calcite.

Its principal localities are the Färöer; Disko in Greenland; in Bohemia, at Eule in clay slate; St. Gothard in Switzerland; the Fassathal; the Kilpatrick hills, near Glasgow; the Hebrides, and the north of Ireland. In India, in the Deccan trap area, at Poona, etc.

Peter's Point, Nova Scotia, affords fine specimens of this species. Found at Phippsburg, Maine. Abundant in many places in the copper veins of Lake Superior in trap, and on I. Royale; on north shore of Lake Superior, between Pigeon Bay and Fond du Lac. Found also at Bergen Hill, N. J.; at the Tilly Foster iron mine, Brewster, N. Y.

Laubanite. $Ca_2Al_2Si_5O_{15} + 6H_2O$. Resembles stilbite. H. = 4·5–5. G. = 2·23. Color snow-white. Occurs upon phillipsite in basalt at Lauban, Silesia.

Chabazite Group. Rhombohedral.

		rr'	$\dot{c}$	
Chabazite	$(Ca,Na_2)Al_2Si_4O_{12} + 6H_2O$, pt.	85° 14′	1·0860	
Gmelinite	$(Na_2Ca)Al_2Si_4O_{12} + 6H_2O$	68° 8′	0·7345	or $\frac{3}{2}\dot{c} = 1·1017$
Levynite	$CaAl_2Si_3O_{10} + 5H_2O$	73° 56′	0·8357	$\frac{4}{3}\dot{c} = 1·1143$

The Chabazite Group includes these three rhombohedral species. The fundamental rhombohedrons have different angles, but, as shown in the axial ratios above, they are closely related, since, taking the rhombohedron of Chabazite as the basis, that of Gmelinite has the symbol $\frac{3}{2}(20\bar{2}3)$ and of Levynite $\frac{4}{3}(30\bar{3}4)$.

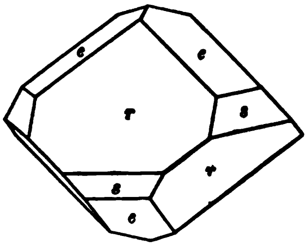
The variation in composition often observed in the first two species has led to the rather plausible hypothesis that they are to be viewed as isomorphous mixtures of the feldspar-like compounds

$(Ca,Na_2)Al_2Si_2O_8 + 4H_2O$, $(Ca,Na_2)Al_2Si_6O_{16} + 8H_2O$.

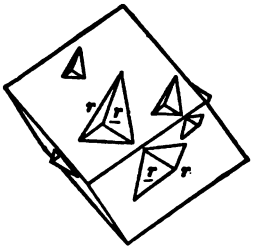
CHABAZITE.

Rhombohedral. Axis $\dot{c}$ = 1·0860; 0001 ∧ $10\bar{1}1$ = 51° $25\frac{3}{4}'$.

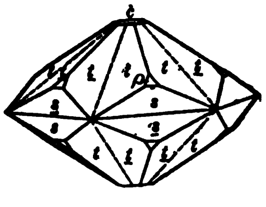
892.



893.



894.



Phacolite.

Twins: (1) tw. axis $\dot{c}$, penetration-twins common. (2) Tw. pl. r, contact-twins, rare. Form commonly the simple rhombohedron varying little in angle from a cube (rr' = 85° 14′); also r and e $(01\bar{1}2)$, (ee' = 54° 47′). Also in complex twins (Fig. 348, p. 118). Also amorphous.

Cleavage: r rather distinct. Fracture uneven. Brittle. H. = 4–5. G. = 2·08–2·16. Luster vitreous. Color white, flesh-red; streak uncolored. Transparent to translucent. Optically −; also + (Andreasberg, also haydenite). Birefringence low. The interference-figure usually confused; sometimes distinctly biaxial; basal sections then divided into sharply defined sectors with different optical orientation. These anomalous optical characters probably secondary and chiefly conditioned by the variation in the amount of water present. Mean refractive index 1·5.

Var.—1. *Ordinary.* The most common form is the fundamental rhombohedron, in which the angle is so near 90° that the crystals were at first mistaken for cubes. *Acadialite,* from Nova Scotia (*Acadia* of the French of last century), is a reddish chabazite; sometimes nearly colorless. *Haydenite* is a yellowish variety in small crystals from Jones's Falls, near Baltimore, Md. 2. *Phacolite* is a colorless variety occurring in twins of hexagonal form (Fig. 894), and lenticular in shape (whence the name, from *φακός, a bean*); the original was from Leipa in Bohemia. Here belongs also *herschelite* (seebachite) from Richmond, Victoria; the composite twins of great variety and beauty. Probably also the original herschelite from Sicily. It occurs in flat, almost tabular, hexagonal prisms with rounded terminations divided into six sectors.

Comp.—Somewhat uncertain, since a rather wide variation is often noted even among specimens from the same locality. The ratio of $(Ca,Na_2,K_2) : Al$ is nearly constant (= 1 : 1), but of $Al_2 : Si$ varies from 1 : 3 to 1 : 5; the water also increases with the increase in silica. The composition usually corresponds to $(Ca,Na_2)Al_2Si_4O_{12} + 6H_2O$, which, if calcium alone is present, requires: Silica 47·4, alumina 20·2, lime 11·1, water 21·3 = 100. If Ca : Na_2 = 1 : 1, the percentage composition is: Silica 47·2, alumina 20·0, lime 5·5, soda 6·1, water 21·2 = 100.

Potassium is present in small amount, also, sometimes, barium and strontium. Streng explains the supposed facts most satisfactorily by the hypothesis that the members of the group are isomorphous mixtures analogous to the feldspars, as noted on p. 453.

Pyr., etc.—B.B. intumesces and fuses to a blebby glass, nearly opaque. Decomposed by hydrochloric acid, with separation of slimy silica.

Diff.—Characterized by rhombohedral form (resembling a cube). It is harder than calcite and does not effervesce with acid; unlike calcite and fluorite in cleavage; fuses B.B. with intumescence unlike analcite.

Obs.—Occurs mostly in basaltic rocks, and occasionally in gneiss, syenite, mica schist, hornblendic schist. Occurs at the Färöer, Greenland, and Iceland, associated with chlorite and stilbite; at Aussig in Bohemia; at Oberstein, with harmotome; at Annerod, near Giessen; at the Giant's Causeway, Antrim, Renfrewshire; Isle of Skye, etc.

In the U. S., in syenite at Somerville, Mass.; at Bergen Hill, N. J., in small crystals; at Jones's Falls near Baltimore (*haydenite*). In Nova Scotia, wine-yellow or flesh-red (the last the *acadialite*), associated with heulandite, analcite and calcite, at Five Islands, Swan's Creek, Digby Neck, etc.

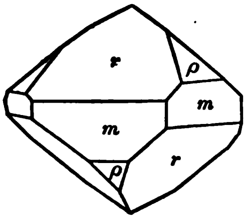
The name *Chabazite* is from χαβᾶζιος, an ancient name of a stone.

GMELINITE.

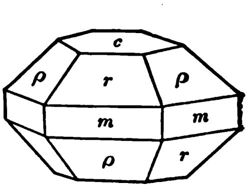
Rhombohedral. Axis $\dot{c}$ = 0·7345.

Crystals usually hexagonal in aspect; sometimes ρ (01$\bar{1}$1) smaller than r (10$\bar{1}$1), and habit rhombohedral; rr′ = 68° 8′, rρ = 37° 44′.

895.



896.



Cleavage: m easy; c sometimes distinct. Fracture uneven. Brittle. H. = 4·5. G. = 2·04–2·17. Luster vitreous. Colorless, yellowish white, greenish white, reddish white, flesh-red. Transparent to translucent. Optically positive, Cyprus, also negative, Andreasberg, the Vicentine, and Glenarm, N. Scotia. Birefringence very low. Interference-figure often disturbed, and basal sections divided optically into section analogous to chabazite.

Comp.—In part $(Na_2,Ca)Al_2Si_4O_{12} + 6H_2O$. If sodium alone is present this requires: Silica 46·9, alumina 19·9, soda 12·1, water 21·1 = 100. See also p. 458.

Pyr., etc.—B.B. fuses easily (F. = 2·5–3) to a white enamel. Decomposed by hydrochloric acid with separation of silica.

Obs.—Occurs in flesh-red crystals in amygdaloidal rocks at Montecchio Maggiore; at Andreasberg; in Transylvania; Antrim, Ireland; Talisker in Skye, in large colorless crystals.

In the United States in fine white crystals at Bergen Hill, N. J. At Cape Blomidon, Nova Scotia (*ledererite*); also at Two Islands and Five Islands.

Named *Gmelinite* after Prof. Ch. Gmelin of Tübingen (1792–1860).

Levynite. $CaAl_2Si_3O_{10}+5H_2O$. In rhombohedral crystals. H. = 4–4·5. G. = 2·09–2·16. Colorless, white, grayish, reddish, yellowish. Found at Glenarm and at Island

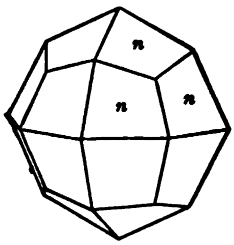
Magee, Antrim; at Dalsnypen, Färöer; in Iceland; in the basalt of Table Mountain near Golden, Colorado.

Offretite. A potash zeolite, related to the species of the chabazite group. In basalt of Mont Simiouse, France.

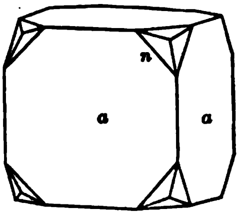
ANALCITE. Analcime.

Isometric. Usually in trapezohedrons; also cubes with faces *n* (211); again the cubic faces replaced by a vicinal trisoctahedron. Sometimes in composite groups about a single crystal as nucleus (Fig. 351, p. 119). Also massive granular; compact with concentric structure.

897.



898.



Cleavage: cubic, in traces. Fracture subconchoidal. Brittle. H. = 5–5·5. G. = 2·22–2·29; 2·278 Thomson. Luster vitreous. Colorless, white; occasionally grayish, greenish, yellowish, or reddish white. Transparent to nearly opaque. Often shows weak double refraction, which is apparently connected with loss of water and consequent change in molecular structure (Art. 411). $n_r = 1·4874$.

Comp.—$NaAlSi_2O_6 + H_2O = Na_2O.Al_2O_3.4SiO_2.2H_2O$ = Silica 54·5, alumina 23·2, soda 14·1, water 8·2 = 100.

Pyr., etc.—Yields water in the closed tube. B.B. fuses at 2·5 to a colorless glass. Gelatinizes with hydrochloric acid.

Diff.—Characterized by trapezohedral form, but is softer than garnet, and yields water B.B., unlike leucite (which is also infusible); fuses without intumescence to a clear glass unlike chabazite.

Recognized in thin sections by its very low relief and isotropic character; often shows optical anomalies. From leucite and sodalite surely distinguished only by chemical tests, i.e., absence of chlorine in the nitric-acid test (see sodalite, p. 444), absence of much potash and abundance of soda in the solution, and evolution of much water from the powder in a closed glass tube below a red heat.

Obs.—Occurs frequently with other zeolites, also prehnite, calcite, etc., in cavities and seams in basic igneous rocks, as basalt, diabase, etc.; also in granite, gneiss, etc. Recently shown to be also a rather widespread component of the groundmass of various basic igneous rocks, at times being the only alkali-alumina silicate present, as in the so-called analcite-basalts. Has been held in such cases to be a primary mineral produced by the crystallization of a magma containing considerable soda and water vapor held under pressure

The Cyclopean Islands, near Catania, Sicily, afford pellucid crystals; also the Fassathal in Tyrol; other localities are, in Scotland, in the Kilpatrick Hills; at Antrim, etc., in Ireland; the Färöer; Iceland; near Aussig, Bohemia; at Arendal, Norway, in beds of iron ore; at Andreasberg, in the Harz, in silver mines.

In the U. S., occurs at Bergen Hill, New Jersey; in gneiss near Yonkers, Westchester Co., N. Y.; abundant in fine crystals, with prehnite, datolite, and calcite, in the Lake Superior region; at Table Mt. near Golden, Colorado, with other zeolites. Nova Scotia affords fine specimens.

The name *Analcime* is from ἀναλκις, *weak*, and alludes to its weak electric power when heated or rubbed. The correct derivative is *analcite*, as here adopted for the species.

Faujasite. Perhaps $H_4Na_2CaAl_4Si_{10}O_{28} + 18H_2O$. In isometric octahedrons. H. = 5. G. = 1·923. Colorless, white. Occurs with augite in the limburgite of Sasbach in the Kaiserstuhl, Baden, etc.

Edingtonite. Perhaps $BaAl_2Si_3O_{10} + 3H_2O$. Crystals pyramidal in habit (tetragonal-sphenoidal); also massive. H. = 4–4·5. G. = 2·694. White, grayish white, pink. Occurs in the Kilpatrick Hills, near Glasgow, Scotland, with harmotome.

Natrolite Group. Orthorhombic and Monoclinic.

		$\breve{a} : \bar{b} : \dot{c}$	
Natrolite	$Na_2Al_2Si_3O_{10} + 2H_2O$	0·9785 : 1 : 0·3536	
		$\grave{a} : \bar{b} : \dot{c}$	β
Scolecite	$Ca(AlOH)_2(SiO_3)_3 + 2H_2O$	0·9764 : 1 : 0·3434	89° 18′
Mesolite	$\left\{\begin{array}{l} Na_2Al_2Si_3O_{10} + 2H_2O \\ 2[CaAl_2Si_3O_{10} + 3H_2O] \end{array}\right.$		

The three species of the NATROLITE GROUP agree closely in angle, though varying in crystalline system; Natrolite is orthorhombic usually, also rarely monoclinic; Scolecite is monoclinic, perhaps also in part triclinic; Mesolite seems to be both monoclinic and triclinic. Fibrous, radiating or divergent groups are common to all these species.

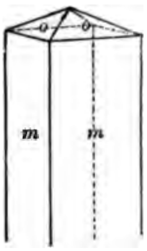
The Natrolite Group includes the sodium silicate, Natrolite, with the empirical formula $Na_2Al_2Si_3O_{10}.2H_2O$; the calcium silicate, Scolecite, $CaAl_2Si_3O_{10}.3H_2O$; also Mesolite intermediate between these and corresponding to $\left\{\begin{array}{l} mNa_2Al_2Si_3O_{10}.2H_2O \\ nCaAl_2Si_3O_{10}.3H_2O \end{array}\right.$.

NATROLITE. Nadelzeolith *Germ.*

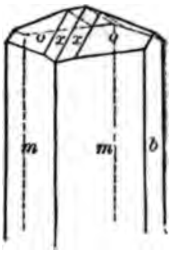
Orthorhombic.* Axes $\grave{a} : \bar{b} : \dot{c}$ = 0·9785 : 1 : 0·3536.

mm‴, $110 \wedge 1\bar{1}0$ = 88° 45½′.
mo′, $110 \wedge 111$ = 63° 11′.
oo′, $111 \wedge \bar{1}11$ = 37° 38′.
oo‴, $111 \wedge \bar{1}\bar{1}1$ = 36° 47½′.

899.



900.



Crystals prismatic, usually very slender to acicular; frequently divergent, or in stellate group. Also fibrous, radiating, massive, granular, or compact.

Cleavage: *m* perfect; *b* imperfect, perhaps only a plane of parting. Fracture uneven. H. = 5–5·5. G. = 2·20–2·25. Luster vitreous, sometimes inclining to pearly, especially in fibrous varieties. Color white, or colorless; to grayish, yellowish, reddish to red. Transparent to translucent. Optically +. Ax. pl. ∥ *b*. Bx ⊥ *c*. $2E_r$ = 93° 28′. β_r = 1·4797; $\gamma - \alpha$ = 0·012.

Var.—*Ordinary.* Commonly either (*a*) in groups of slender colorless prismatic crystals, varying but little in angle from square prisms, often acicular, or (*b*) in fibrous divergent or radiated masses, vitreous in luster, or but slightly pearly (these radiated forms often resemble those of thomsonite and pectolite); often also (*c*) solid amygdules, usually radiated fibrous, and somewhat silky in luster within; (*d*) rarely compact massive. *Galactite* is ordinarily natrolite, in colorless needles from southern Scotland.

Bergmannite, spreustein, brevicite, are names which have been given to the natrolite from the augite-syenite of southern Norway, on the Langesund fiord, in the "Brevik" region, where it occurs fibrous, massive, and in long prismatic crystallizations, and from white to red in color. Derived in part from elæolite, in part from sodalite. *Iron-natrolite* is a dark green opaque variety, either crystalline or amorphous, from the Brevik region; the iron is due to inclusions.

Comp.—$Na_2Al_2Si_3O_{10} + 2H_2O$ or $Na_2O.Al_2O_3.3SiO_2 + 2H_2O$ = Silica 47·4, alumina 26·8, Na_2O 16·3, water 9·5 = 100.

Pyr., etc.—In the closed tube whitens and becomes opaque. B.B. fuses quietly at 2 to a colorless glass. Fusible in the flame of an ordinary stearine or wax candle. Gelatinizes with acids.

Diff.—Distinguished from aragonite and pectolite by its easy fusibility and gelatinization with acid.

Obs.—Occurs in cavities in amygdaloidal basalt, and other related igneous rocks;

---

* In rare cases the crystals seem to be monoclinic.

sometimes in seams in granite, gneiss, and syenite. Found at Aussig and Teplitz in Bohemia; in fine crystals in Auvergne; Fassathal, Tyrol; Kapnik, Hungary. In red amygdules (*crocalite*) in amygdaloid of Ireland, Scotland and Tyrol; the amygdaloid of Bishoptown (*galactite*); at Glen Farg (*fargite*) in Fifeshire. Common in the augite-syenite of the Langesund fiord, near Brevik, southern Norway.

In North America, in the trap of Nova Scotia; at Bergen Hill, N. J.; at Copper Falls, Lake Superior.

Named *Mesotype* by Haüy, from *μέσος*, *middle*, and *τύπος*, *type*, because the form of the crystal—in his view a square prism—was intermediate between the forms of stilbite and analcite. *Natrolite*, of Klaproth, is from *natron*, *soda;* it alludes to the presence of soda, whence also the name *soda-mesotype*, in contrast with scolecite, or *lime-mesotype*.

SCOLECITE.

Monoclinic. Axes $\grave{a} . \bar{b} : \dot{c} = 0{\cdot}9764 : 1 : 0{\cdot}3434$; $\beta = 89^\circ\ 18'$.

Crystals slender prismatic ($mm''' = 88^\circ\ 37\frac{1}{2}'$), twins showing a feather-like striation on *b*, diverging upward; also as penetration-twins. Crystals in divergent groups. Also massive, fibrous and radiated, and in nodules.

Cleavage: *m* nearly perfect. H. = 5–5·5. G. = 2·16–2·4. Luster vitreous, or silky when fibrous. Transparent to subtranslucent. Optically –. Ax. pl. and $Bx_o \perp b$. $Bx_a \wedge \dot{c} = 15^\circ$–$16^\circ$. $2H_{a.r} = 32^\circ\ 26'$. $\beta = 1{\cdot}4952$.

Comp.—$CaAl_2Si_3O_{10} + 3H_2O$ or $CaO.Al_2O_3.3SiO_2.3H_2O$ = Silica 45·9, alumina 26·0, lime 14·3, water 13·8 = 100.

Pyr., etc.—B.B. sometimes curls up like a worm (whence the name from *σκώληξ*, *a worm*, which gives *scolecite*, and not *scolesite* or *scolezite*); other varieties intumesce but slightly, and all fuse at 2–2·2 to a white blebby enamel. Gelatinizes with acids like natrolite.

Obs.—Occurs in the Berufiord, Iceland; in amygdaloid at Staffa; in Skye, at Talisker; near Eisenach, Saxony; in Auvergne; common in fine crystallizations in the Deccan trap area, in British India. In the United States, in *Colorado* at Table Mountain near Golden in cavities in basalt. In Canada, at Black Lake, Megantic Co., Quebec.

Mesolite. Intermediate between natrolite and scolecite (see p. 432). In acicular and capillary crystals; delicate divergent tufts, etc. G. = 2·29. White or colorless. In amygdaloidal basalt at numerous points.

THOMSONITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}9932 : 1 : 1{\cdot}0066$.

Distinct crystals rare; in prisms, $mm''' = 89^\circ\ 37'$. Commonly columnar, structure radiated; in radiated spherical concretions; also closely compact.

Cleavage: *b* perfect; *a* less so; *c* in traces. Fracture uneven to subconchoidal. Brittle. H. = 5–5·5. G. = 2·3–2·4. Luster vitreous, more or less pearly. Snow-white; reddish, green; impure varieties brown. Streak uncolored. Transparent to translucent. Pyroelectric. Optically +. Ax. pl. ‖ *c*. $Bx \perp b$. Dispersion $\rho > v$ strong. $2E_r = 82^\circ$. $\beta_r = 1{\cdot}503$.

Var.—1. *Ordinary*. (*a*) In regular crystals, usually more or less rectangular in outline, prismatic in habit. (*b*) Prisms slender, often vesicular to radiated. (*c*) Radiated fibrous. (*d*) Spherical concretions, consisting of radiated fibers or slender crystals. Also massive, granular to impalpable, and white to reddish brown, less often green as in *lintonite*. The spherical massive forms also radiated with several centers and of varying colors, hence of much beauty when polished. *Ozarkite* is a white massive thomsonite from Arkansas.

Comp.—$(Na_2,Ca)Al_2Si_2O_8 + \frac{5}{2}H_2O$ or $(Na_2,Ca)O.Al_2O_3.2SiO_2.\frac{5}{2}H_2O$. The ratio of Na_2 : Ca varies from 3 : 1 to 1 : 1. If Ca : Na_2 = 3 : 1 the percentage composition requires: SiO_2 37·0, Al_2O_3 31·4, CaO 12·9, Na_2O 4·8, H_2O 13·9 = 100.

Pyr., etc.—B.B. fuses with intumescence at 2 to a white enamel. Gelatinizes with hydrochloric acid.

Diff.—Resembles some natrolite, but fuses to an opaque not to a clear glass.

Obs.—Found in cavities in lava in amygdaloidal igneous rocks, sometimes with elæolite as a result of its alteration. Occurs near Kilpatrick, Scotland; in the lavas of Somma (*comptonite*); in basalt at the Pflasterkaute in Saxe Weimar; in Bohemia, in phonolite; the Cyclopean islands, Sicily; near Brevik, Norway; the Färöer; Iceland (carpho-stilbite, straw-yellow); at Mt. Monzoni, Fassathal.

Occurs at Peter's Point, Nova Scotia. In the U. S. at Magnet Cove (*ozarkite*) in the Ozark Mts., Arkansas; in the amygdaloid of Grand Marais, L. Superior, which yields the water-worn pebbles resembling agate, in part green (*lintonite*); in the basalt of Table Mt. near Golden, Colo.

Hydronephelite. $HNa_2Al_3Si_3O_{12} + 3H_2O$. Massive, radiated. H. = 4·5–6. G = 2·263. Color white; also dark gray. From Litchfield, Maine. *Ranite* from the Langesund fiord, Norway, is similar.

II. Mica Division.

The species embraced under this Division fall into three groups: 1, the Mica Group, including the Micas proper; 2, the Clintonite Group, or the Brittle Micas; 3, the Chlorite Group. Supplementary to these are the Vermiculites, hydrated compounds chiefly results of the alteration of some one of the micas.

All of the above species have the characteristic micaceous structure, that is, they have highly perfect basal cleavage and yield easily thin laminæ. They belong to the monoclinic system, but the position of the bisectrix in general deviates but little from the normal to the plane of cleavage; all of them show on the basal section plane angles of 60° or 120°, marking the relative position of the chief zones of forms present, and giving them the appearance of hexagonal or rhombohedral symmetry; further, they are more or less closely related among themselves in the angles of prominent forms.

The species of this Division all yield water upon ignition, the micas mostly from 4 to 5 p. c., the chlorites from 10 to 13 p. c.; this is probably to be regarded in all cases as water of constitution, and hence they are not properly *hydrous* silicates.

More or less closely related to these species are those of the Serpentine and Talc Division and the Kaolin Division following, many of which show distinctly a mica-like structure and cleavage and also pseudo-hexagonal symmetry.

1. Mica Group. Monoclinic.

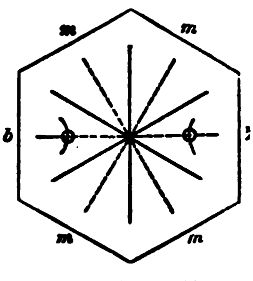
Muscovite	Potassium Mica	$H_2KAl_3(SiO_4)_3$
		$\grave{a} : \breve{b} : \grave{c} = 0{\cdot}57735 : 1 : 3{\cdot}3128 \quad \beta = 89^\circ\ 54'$
Paragonite	Sodium Mica	$H_2NaAl_3(SiO_4)_3$
Lepidolite	Lithium Mica	$KLi[Al(OH,F)_2]Al(SiO_3)_3$, pt.
Zinnwaldite	Lithium-iron Mica	
Biotite	Magnesium-iron Mica	$(H,K)_2(Mg,\overset{\text{II}}{Fe})_2(Al,\overset{\text{III}}{Fe})_2(SiO_4)_3$, pt.
		$\grave{a} : \breve{b} : \grave{c} = 0{\cdot}57735 : 1 : 3{\cdot}2743 \quad \beta = 90^\circ\ 0'$
Phlogopite		$(H,K,(MgF))_3Mg_3Al(SiO_4)_3$
	Magnesium Mica; usually containing fluorine, nearly free from iron.	
Lepidomelane	Annite	
	Iron Micas. Contain ferric iron in large amount.	

The species of the Mica Group crystallize in the monoclinic system, but with a close approximation to either rhombohedral or orthorhombic symmetry; the plane angles of the base are in all cases 60° or 120°. They are all characterized by highly perfect basal cleavage, yielding very thin, tough, and more or less elastic laminæ. The negative bisectrix, $\mathfrak{a}$, is very nearly normal to the basal plane, varying at most but a few degrees from this; hence a cleavage plate shows the axial interference-figure, which for the pseudo-rhombohedral kinds is often uniaxial or nearly uniaxial. Of the species named above, biotite has usually a very small axial angle, and is often sensibly unaxial; the axial angle of phlogopite is also small, usually 10° to 12°; for muscovite, paragonite, lepidolite the angle is large, in air commonly from 50° to 70°.

The Micas may be referred to the same fundamental axial ratio with an angle of obliquity differing but little from 90°; they show to a considerable extent the same forms, and their isomorphism is further indicated by their not infrequent intercrystallization in parallel position, as biotite with muscovite, lepidolite with muscovite, etc.

A blow with a somewhat dull-pointed instrument on a cleavage plate of mica develops in all the species a six-rayed *percussion-figure* (Fig. 901. also Fig. 477, p. 149), two lines of which are nearly parallel to the prismatic edges; the third, which is the most strongly characterized (Leitstrahl *Germ.*), is parallel to the clinopinacoid or plane of symmetry. The micas are often divided into two classes, according to the position of the plane of the optic axes. In the *first class* belong those kinds for which the optic axial plane is normal to *b* (010), the plane of symmetry (Fig. 901); in the *second class* the axial plane is parallel to the plane of symmetry. The percussion-figure serves to fix the crystallographic orientation when crystalline faces are wanting. A second series of lines at right angles to those mentioned may be more or less distinctly developed by pressure of a dull point on an elastic surface, forming the so-called *pressure-figure;* this is sometimes six-rayed, more often shows three branches only, and sometimes only two are developed. In Fig. 901 the position of the pressure-figure is indicated by the dotted lines. These lines are connected with gliding-planes inclined some 67° to the plane of cleavage (see beyond).

901.



The micas of the *first class* include: Muscovite, paragonite, lepidolite, also some rare varieties of biotite called anomite.

The *second class* embraces: Zinnwaldite and most biotite, including lepidomelane and phlogopite.

Chemically considered, the micas are silicates, and in most cases orthosilicates, of aluminium with potassium and hydrogen, also often magnesium, ferrous iron, and in certain cases ferric iron, sodium, lithium (rarely rubidium and cæsium); further, rarely, barium, manganese, chromium. Fluorine is prominent in some species, and titanium is also sometimes present. Other elements (boron, etc.) may be present in traces. All micas yield water upon ignition in consequence of the hydrogen (or hydroxyl) which they contain.

MUSCOVITE. Common Mica. Potash Mica. Kaliglimmer *Germ.*

Monoclinic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}57735 : 1 : 3{\cdot}3128$; $\beta = 89° 54'$.

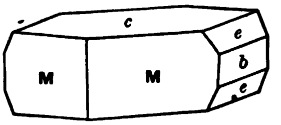
Twins common according to the *mica-law:* tw. plane a plane in the zone *cM* normal to *c*, the crystals often united by *c*. Crystals rhombic or hexagonal in outline with plane angles of 60° or 120°. Habit tabular, passing into tapering forms with planes more or less rough and strongly striated horizontally;

vicinal forms common. Folia often very small and aggregated in stellate, plumose, or globular forms; or in scales, and scaly massive; also cryptocrystalline and compact massive.

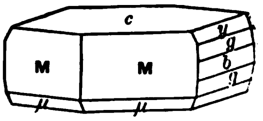
Cleavage: basal, eminent. Also planes of secondary cleavage as shown in the percussion-figure (see pp. 464 and 149); natural plates hence often yield narrow strips or thin fibers ∥ axis *b*, and less distinct in directions inclined 60° to this. Thin laminæ flexible and elastic when bent, very tough, harsh to the touch, passing into kinds which are less elastic and have a more or less unctuous or talc-like feel. Etching-figures on *c* monoclinic in symmetry (Fig. 481, p. 150).

cM, $001 \wedge 221 = 85^\circ\ 36'$.
$c\mu$, $001 \wedge \bar{1}11 = 81^\circ\ 30'$.
MM', $221 \wedge 2\bar{2}1 = 59^\circ\ 48'$.
$\mu\mu'$, $\bar{1}11 \wedge \bar{1}\bar{1}1 = 59^\circ\ 16\frac{1}{2}'$.

902.



903.



H. = 2·2–5. G. = 2·76–3. Luster vitreous to more or less pearly or silky. Colorless, gray, brown, hair-brown, pale green, and violet, yellow, dark olive-green, rarely rose-red. Streak uncolored. Transparent to translucent.

Pleochroism usually feeble; distinct in some deep-colored varieties (see beyond). Absorption in the direction normal to the cleavage plane (vibrations ∥ $\mathfrak{b}$, $\mathfrak{c}$) strong, much more so than transversely (vibrations ∥ $\mathfrak{a}$); hence a crystal unless thin is nearly or quite opaque in the first direction though translucent through the prism. Optically −. Ax. pl. ⊥ *b* and nearly ⊥ *c*. Bx_a (= $\mathfrak{a}$) inclined about − 1° (behind) to a normal to *c*. Dispersion $\rho > v$. Axial angle variable, usually about 70°, but diminishing to 50° in kinds (phengite) relatively high in silica. Birefringence rather high, $\gamma - \alpha = 0{\cdot}039$; $\beta_y = 1{\cdot}5941$.

Var.—1. ***Ordinary Muscovite.*** In crystals as above described, often tabular ∥ *c*, also tapering with vertical faces rough and striated; the basal plane often rough unless as developed by cleavage. More commonly in plates without distinct outline, except as developed by pressure (see above); the plates sometimes very large, but passing into fine scales, arranged in plumose or other forms. In normal muscovite the thin laminæ spring back with force when bent, the scales are more or less harsh to the touch, unless very small, and a pearly luster is seldom prominent.

2. DAMOURITE. Including *margarodite*, *gilbertite*, *hydro-muscovite*, and most HYDROMICA in general. Folia less elastic; luster somewhat pearly or silky and feel unctuous like talc. The scales are usually small and it passes into forms which are fine scaly or fibrous, as *sericite*, and finally into the compact crypto-crystalline kinds called *oncosine*, including much *pinite*. Axial angle for damourite chiefly from 60° to 70°. Often derived by alteration of cyanite, topaz, corundum, etc. Although often spoken of as *hydrous* micas, it does not appear that damourite and the allied varieties necessarily contain more water than ordinary muscovite; they may, however, give it off more readily.

Margarodite, as originally named, was the talc-like mica of Mt. Greiner in the Zillerthal; granular to scaly in structure, luster pearly, color grayish white. *Gilbertite* occurs in whitish, silky forms from the tin mine of St. Austell, Cornwall. *Sericite* is a fine scaly muscovite united in fibrous aggregates and characterized by its silky luster (hence the name from σηρικός, *silky*.

Comp., Var.—For the most part an orthosilicate of aluminium and potassium $(H,K)AlSiO_4$. If, as in the common kinds, H : K = 2 : 1, this becomes $H_2KAl_3(SiO_4)_3 = 2H_2O.K_2O.3Al_2O_3.6SiO_2$ = Silica 45·2, alumina 38·5, potash 11·8, water 4·5 = 100.

Some kinds give a larger amount of silica (47 to 49 p. c.) than corresponds to a normal orthosilicate, and they have been called *phengite*. As shown by Clarke, these acid muscovites can be most simply regarded as molecular mixtures of $H_2KAl_3(SiO_4)_3$ and $H_2KAl_3(Si_3O_8)_3$.

Iron is usually present in small amount only. Barium is rarely present, as in *oellacherite*. G. = 2·88–2·99. Chromium is also present in *fuchsite* from Schwarzenstein, Zillerthal, and elsewhere.

Pyr., etc.—In the closed tube gives water, which with Brazil-wood often reacts for fluorine. B.B. whitens and fuses on the thin edges (F. = 5·7, v. Kobell) to a gray or yellow glass. With fluxes gives reactions for iron and sometimes manganese, rarely chromium. Not decomposed by acids. Decomposed on fusion with alkaline carbonates.

Diff.—Distinguished in normal kinds from all but the species of this division by the perfect basal cleavage and micaceous structure; the pale color separates it from most biotite; the laminæ are more flexible and elastic than those of phlogopite and still more than those of the brittle micas and the chlorites.

In thin sections recognized by want of color and by the perfect cleavage shown by fine lines (as in Fig. 907, p. 344) in sections ⊥ *c*, in a direction parallel to *c*. By reflected light under the microscope the same sections show a peculiar mottled surface with satin-like luster; birefringence rather high, hence interference-colors bright.

Obs.—Muscovite is the most common of the micas. It is an essential constituent of mica schist and related rocks, and is a prominent component of certain common varieties of granite and gneiss; also found at times in fragmental rocks and limestones; in volcanic rocks it is rare and appears only as a secondary product. The largest and best developed crystals occur in the pegmatite dikes associated with granitic intrusions, either directly cutting the granite or in its vicinity. Often in such occurrences in enormous plates from which the mica or "isinglass" of commerce is obtained. It is then often associated with crystallized orthoclase, quartz, albite; also apatite, tourmaline, garnet, beryl, columbite, etc., and other mineral species characteristic of granitic veins. Further, muscovite often encloses flattened crystals of garnet, tourmaline, also quartz in thin plates between the sheets; further not infrequently magnetite in dendrite-like forms following in part the directions of the percussion-figure.

Some of the best known localities, are: Abühl in the Sulzbachthal, with adularia; Rothenkopf in the Zillerthal, Tyrol; Soboth, Styria; St. Gothard, Binnenthal, and elsewhere in Switzerland; Mourne Mts., Ireland; Cornwall; Utö, Falun, Sweden; Skutterud, Norway. Obtained in large plates from Greenland and the East Indies.

In *Maine*, at Mount Mica in the town of Paris; at Buckfield, in fine crystals. In *N. Hamp.*, at Acworth, Grafton. In *Mass.*, at Chesterfield; South Royalston; at Goshen, rose-red. In *Conn.*, at Monroe; at Litchfield, with cyanite; at the Middletown feldspar quarry; at Haddam; at Branchville, with albite, etc.; New Milford. In *N. York*, near Warwick; Edenville; Edwards. In *Penn.*, at Pennsbury, Chester Co.; at Unionville, Delaware Co., and at Middletown. In *Maryland*, at Jones's Falls, Baltimore. In *Virginia*, at Amelia Court-House. In *No. Carolina*, extensively mined at many places in the western part of the state; the chief mines are in Mitchell, Yancey, Jackson and Macon Cos. The mica mines have also afforded many rare species, as columbite, samarskite, hatchettolite, uraninite, etc.; in good crystals in Alexander Co. In *S. Carolina*, there are also muscovite deposits; also in Georgia and Alabama.

Mica mines have also been worked to some extent in the Black Hills, South Dakota; in Washington, at Rockford, Spokane Co.; in Colorado.

Muscovite is named from *Vitrum Muscoviticum* or *Muscovy-glass*, formerly a popular name of the mineral.

Pinite. A general term used to include a large number of alteration-products especially of iolite, also spodumene, nephelite, scapolite, feldspar and other minerals. In composition essentially a hydrous silicate of aluminium and potassium corresponding more or less closely to muscovite, of which it is probably to be regarded as a massive, compact variety, usually very impure from the admixture of clay and other substances. Characters as follows: Amorphous; granular to cryptocrystalline. Rarely a submicaceous cleavage. H. = 2·5–3·5. G. = 2·6–2·85. Luster feeble, waxy. Color grayish white, grayish green, pea-green, dull green, brownish, reddish. Translucent to opaque. The following are some of the minerals classed as pinite: *gigantolite*, *gieseckite* (see p. 355), *liebenerite*, *dysyntribite*, *parophite*, *rosite*, *polyargite*, *wilsonite*, *killinite*.

Agalmatolite (pagodite) is like ordinary massive pinite in its amorphous compact texture, luster, and other physical characters, but contains more silica, which may be from free quartz or feldspar as impurity. The Chinese has H. = 2–2·5; G. = 2·785–2·815. Colors usually grayish, grayish green, brownish, yellowish. Named from ἄγαλμα, *an image;*

pagodite is from *pagoda*, the Chinese carving the soft stone into miniature pagodas, images, etc. Part of the so-called agalmatolite of China is true pinite in composition, another part is compact pyrophyllite, and still another steatite (see these species).

Paragonite. A sodium mica, corresponding to muscovite in composition; formula, $H_2NaAl_3(SiO_4)_3$. In fine pearly scales; also compact. G. = 2·78–2·90. Color yellowish, grayish, greenish; constitutes the mass of the rock at Monte Campione near Faido in Canton Tessin, Switzerland, containing cyanite and staurolite; called paragonite-schist. Occurs associated with tourmaline and corundum at Unionville, Delaware Co., Pa.

LEPIDOLITE. Lithia Mica. Lithionglimmer *Germ.*

In aggregates of short prisms, often with rounded terminal faces. Crystals sometimes twins or trillings according to the mica law. Also in cleavable plates, but commonly massive scaly-granular, coarse or fine.

Cleavage: basal, highly eminent. H. = 2·5–4. G. = 2·8–2·9. Luster pearly. Color rose-red, violet-gray or lilac, yellowish, grayish white, white. Translucent. Optically –. Ax. pl. usually ⊥ *b*; rarely ∥ *b*. Bx_a (𝔞) inclined 1° 47′ red, and 1° 33½′ yellow (Na) to normal to *c*. Axial angle large, from 50°–72°, $\beta = 1·5975$.

Comp.—In part a metasilicate, $\overset{\text{I}}{R}_3Al(SiO_3)_3$ or $KLi[Al(OH,F)_2]Al(SiO_3)_3$. The ratio of fluorine and hydroxyl is variable. The following are analyses (Riggs):

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	K_2O	Li_2O	Na_2O	H_2O	F	
Paris,	50·92	24·99	0·30	0·23	*tr.*	11·38	4·20	2·11	1·96	6·29	= 102·38
Hebron,	48·80	28·30	0·29	0·09	0·08	12·21[a]	4·49	0·74	1·73	4·96	
									[CaO,MgO	0·17	= 101·86

[a] With 0·77 $(Rb,Cs)_2O$.

Pyr., **etc.**—In the closed tube gives water and reaction for fluorine. B.B. fuses with intumescence at 2–2·5 to a white or grayish glass, sometimes magnetic, coloring the flame purplish red at the moment of fusion (lithia). With the fluxes some varieties give reactions for iron and manganese. Attacked but not completely decomposed by acids. After fusion, gelatinizes with hydrochloric acid.

Obs.—Occurs in granite and gneiss, especially in granitic veins; often associated with lithia tourmaline; also with amblygonite, spodumene, cassiterite, etc.; sometimes associated with muscovite in parallel position.

Found near Utö in Sweden; Penig, Saxony; Rozena (or Rožna), Moravia, etc. In the United States, common in the western part of Maine, in Hebron, Auburn, Paris, etc.; at Chesterfield, Mass.; Middletown, Conn.; with rubellite near San Diego, California.

Named lepidolite from λεπίς, *scale*, after the earlier German name *Schuppenstein*, alluding to the scaly structure of the massive variety of Rozena.

COOKEITE is a micaceous mineral occurring in rounded aggregations on rubellite, also with lepidolite, tourmaline, etc., at Hebron, Me. Composition $Li[Al(OH)_2]_3(SiO_3)_2$.

Zinnwaldite. An iron-lithia mica in form near biotite. Color pale violet, yellow to brown and dark gray. Occurs at Zinnwald and Altenberg; similarly in Cornwall.

Cryophyllite is a related lithium mica from Rockport, Mass. *Polylithionite* is a lithium mica from Kangerdluarsuk, Greenland.

BIOTITE.

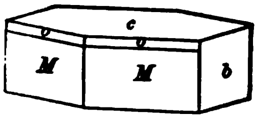
Monoclinic; pseudo-rhombohedral. Axes $\grave{a} : \bar{b} : \acute{c} = 0·57735 : 1 : 3·2743$; $\beta = 90°$.

Habit tabular or short prismatic; the pyramidal faces often repeated in oscillatory combination. Crystals often apparently rhombohedral in symmetry since *r* (101) and *z* (132), *z′* ($1\bar{3}2$), which are inclined to *c* at sensibly the same angle, often occur together; further, the zones to which these faces belong are inclined 120° to each other, hence the hexagonal outline of basal sections. Twins, according to the mica law, tw. pl. a plane in the prismatic

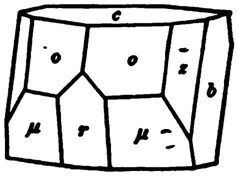
zone $\perp c$. Often in disseminated scales, sometimes in massive aggregations of cleavable scales.

co, $001 \wedge 112 = 73^\circ\ 1'$. *cr*, $001 \wedge \bar{1}01 = 80^\circ\ 0'$.
cM, $001 \wedge 221 = 85^\circ\ 38'$. *cz*. $001 \wedge 132 = 80^\circ\ 0'$.
cμ, $001 \wedge \bar{1}11 = 81^\circ\ 19'$. *MM'*, $221 \wedge \bar{2}21 = 59^\circ\ 48\frac{1}{2}'$.

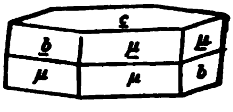
904.



905.



906.



Cleavage: basal, highly perfect; planes of separation shown in the percussion-figure; also gliding-planes $\rho\,(\bar{2}05)$, ζ (135) shown in the pressure-figure inclined about 66° to *c* and yielding pseudo-crystalline forms (Fig. 475, p. 148). H. = 2·5–3. G. = 2·7–3·1. Luster splendent, and more or less pearly on a cleavage surface, and sometimes submetallic when black; lateral surfaces vitreous when smooth and shining. Colors usually green to black, often deep black in thick crystals, and sometimes even in thin laminæ, unless the laminæ are very thin; such thin laminæ green, blood-red, or brown by transmitted light; also pale yellow to dark brown; rarely white. Streak uncolored. Transparent to opaque.

Pleochroism strong; absorption $\mathfrak{b} = \mathfrak{c}$ nearly, for $\mathfrak{a}$ much stronger. Hence sections $\parallel c$ (001) dark green or brown to opaque; those $\perp c$ lighter and deep brown or green for vibrations $\parallel c$, pale yellow, green or red for vibrations $\perp c$. Pleochroic halos often noted, particularly about microscopic inclusions. Optically −. Ax. pl. usually $\parallel b$, rarely $\perp b$. Bx_a ($= \mathfrak{a}$) nearly coincident with the normal to *c*, but inclined about half a degree, sometimes to the front, sometimes the reverse. Axial angle usually very small, and often sensibly uniaxial; also up to 50°. Birefringence high, $\gamma - \alpha = 0{\cdot}04$ to $0{\cdot}06$.

Comp., Var.—In most cases an orthosilicate, chiefly ranging between $(H,K)_2(Mg,Fe)_4(Al,Fe)_2(SiO_4)_4$ and $(H,K)_2(Mg,Fe)_2Al_2(SiO_4)_3$. Of these the second formula may be said to represent typical biotite. The amount of iron varies widely.

Biotite is divided into two classes by Tschermak:

I. MEROXENE. Axial plane $\parallel b$. II. ANOMITE. Ax. pl. $\perp b$. Of these two kinds, meroxene includes nearly all ordinary biotite, while anomite is, so far as yet observed, of restricted occurrence, the typical localities being Greenwood Furnace, Orange Co., N. Y., and L. Baikal in E. Siberia. *Meroxene* is a name early given to the Vesuvian biotite. Anomite is from *ανομος*, contrary to law.

Haughtonite and *Siderophyllite* are kinds of biotite containing much iron.

Manganophyllite is a manganesian biotite. Occurs in aggregations of thin scales. Color bronze- to copper-red. Streak pale red. From Pajsberg and Långban, Sweden; Piedmont, Italy.

The following are typical analyses of biotite: 1, by Berwerth; 2, by Rammelsberg; 3, by Smith and Brush.

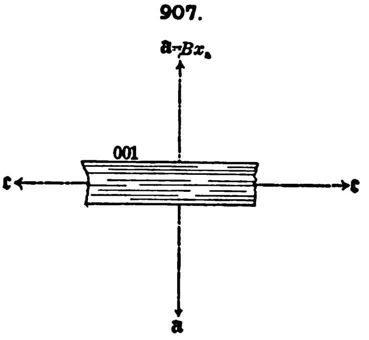
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	H_2O	F
1. Vesuvius	39·30	16·95	0·48	8·45	21·89	0·82	7·79	0·49	4·02	0·89
										[= 101·08
2. Miask, *black*	32·49	12·34	6·56	25·13	5·29	–	9·59	0·88	2·42	1·61
										[TiO_2 4·03 = 100·34
3. *Anomite*, Greenwood F.	39·88	14·99	7·68	–	23·69	–	9·11	1·12	1·30	0·95
										[Cl 0·44 = 99·16

Pyr., etc.—In the closed tube gives a little water. Some varieties give the reaction for fluorine in the open tube; some kinds give little or no reaction for iron with the fluxes, while others give strong reactions for iron. B.B. whitens and fuses on the thin edges. Completely decomposed by sulphuric acid, leaving the silica in thin scales.

Diff.—Distinguished by its dark green to brown and black color and micaceous structure, usually nearly uniaxial.

Recognized in thin sections by its brown (or green) color; strong pleochroism and strong absorption parallel to the elongation (unlike tourmaline). Sections $\parallel c$ are non-pleochroic, commonly exhibit more or less distinct hexagonal outlines and yield a negative sensibly uniaxial figure. Sections $\perp c$ are strongly pleochroic and are marked by fine parallel cleavage lines (Fig. 907); they also have nearly parallel extinction, and show high polarization colors; by reflected light they exhibit a peculiar mottled or watered sheen which is very characteristic and aids in distinguishing them from brown hornblende.

907.



Section $\perp c$.

Obs.—Biotite is an important constituent of many different kinds of igneous rocks, especially those formed from magmas containing considerable potash and magnesia. Common in certain varieties of granites, syenite, diorite, etc., of the massive granular type; also in rhyolite, trachyte, and andesite among the lavas; in minettes, kersantites, etc. It occurs also as the product of metamorphic action in a variety of rocks. It is not infrequently associated in parallel position with muscovite, the latter, for example, forming the outer portions of plates having a nucleus of biotite.

Some of the prominent localities of crystallized biotite are as follows: Vesuvius, common particularly in ejected limestone masses on Monte Somma, with augite, chrysolite, nephelite, humite, etc. The crystals are sometimes nearly colorless or yellow and then usually complex in form; also dark green to black; Mt. Monzoni in the Fassathal; Schwarzenstein, Zillerthal; Rezbánya and Morawitza in Hungary; Schelingen and other points in the Kaiserstuhl; the Laacher See; on the west side of L. Ilmen near Minsk, etc.

In the United States ordinary biotite is common in granite, gneiss, etc.; but notable localities of distinct crystals are not numerous. It occurs with muscovite (wh. see) as a more or less prominent constituent of the pegmatite veins in the New England States; also Pennsylvania, Virginia, North Carolina. *Siderophyllite* is from the Pike's Peak region.

CASWELLITE. An altered biotite from Franklin Furnace, N. J.

PHLOGOPITE.

Monoclinic. In form and angles near biotite. Crystals prismatic, tapering; often large and coarse; in scales and plates.

Cleavage: basal, highly eminent. Thin laminæ tough and elastic. H. = 2·5–3. G. = 2·78–2·85. Luster pearly, often submetallic on cleavage surface. Color yellowish brown to brownish red, with often something of a copper-like reflection; also pale brownish yellow, green, white, colorless. Often exhibits asterism in transmitted light, due to regularly arranged inclusions. Pleochroism distinct in colored varieties: $\mathfrak{c}$ brownish red, $\mathfrak{b}$ brownish green, $\mathfrak{a}$ yellow. Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$, Burgess. Optically −. Ax. pl. $\parallel b$. Bx_a nearly $\perp c$. Axial angle (2E) small but variable even in the same specimen, from 0° to 17° 25′ for red. Dispersion $\rho < v$. The axial angle appears to increase with the amount of iron.

A magnesium mica, near biotite, but containing little iron; potassium is prominent as in all the micas, and in most cases fluorine. Typical phlogopite, according to Clarke, is $\overset{\text{I}}{R}_3Mg_3Al(SiO_4)_3$, where $\overset{\text{I}}{R} = H,K,MgF$. Analyses: 1 by Penfield; 2 by Clarke and Schneider.

			SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	BaO	K_2O	Na_2O	H_2O	F	
Edwards	2·792	§	44·81	10·87	—	0·31	28·90	—	8·40	0·46[a]	5·42	—	ign (100°) 0·96 [= 100·18
Burgess			39·66	17·00	0·27	0·20	26·49	0·62	9·97	0·60	2·99	2·24	Ti_2O 0·56 [= 100·60

[a] With 0·08 Li_2O.

Obs.—Phlogopite is especially characteristic of crystalline limestone or dolomite. It is often associated with pyroxene, amphibole, serpentine, etc. Thus as at Pargas, Finland; in St. Lawrence Co. and Jefferson Co., N. Y.; also Burgess, Ontario, and elsewhere in Canada.

Named from *φλογωπός*, *fire-like*, in allusion to the color.

The asterism of phlogopite, seen when a candle-flame is viewed through a thin sheet, is a common character, particularly prominent in the kinds from northern New York and Canada. It has been shown to be due to minute acicular inclusions, rutile or tourmaline, arranged chiefly in the direction of the rays of the pressure-figure, producing a distinct six-rayed star; also parallel to the lines of the percussion-figure, giving a secondary star, usually less prominent than the other.

Lepidomelane. Near biotite, but characterized by the large amount of ferric iron present. *Annite* from Cape Ann, Mass., belongs here. In small six-sided tables, or an aggregate of minute scales. H. = 3. G. = 3·0–3·2. Color black, with occasionally a leek-green reflection.

Alurgite. A manganese mica from St. Marcel. Piedmont.

Roscoelite. A vanadium mica; formula doubtful. In minute scales; structure micaceous. G. = 2·92–2·94. Color clove-brown to greenish brown. Occurs at the gold mine at Granite Creek, El Dorado Co., California.

2. Clintonite Group. Monoclinic.

The minerals here included are sometimes called the Brittle Micas. They are near the micas in cleavage, crystalline form and optical properties, but are marked physically by the brittleness of the laminæ, and chemically by their basic character.

In several respects they form a transition from the micas proper to the chlorites. Margarite, or calcium mica, is a basic silicate of aluminium and calcium, while Chloritoid is a basic silicate of aluminium and ferrous iron (with magnesium), like the chlorites.

MARGARITE. Kalkglimmer *Germ.*

Monoclinic. Rarely in distinct crystals. Usually in intersecting or aggregated laminæ; sometimes massive, with a scaly structure.

Cleavage: basal, perfect. Laminæ rather brittle. H. = 3·5–4·5. G. = 2·99–3·08. Luster of base pearly, of lateral faces vitreous. Color grayish, reddish white, pink, yellowish. Translucent, subtranslucent.

Optically —. Ax. pl. $\perp$ *b*. Bx_a approximately $\perp$ *c*, but varying more widely than the ordinary micas. $\mathfrak{a}\ c = +6\frac{1}{2}°$. Dispersion $\rho < v$. Axial angle large, from 100° to 120° in air. Refractive index $\beta = 1·64–1·65$.

Comp. — $H_2CaAl_4Si_2O_{12}$ = Silica 30·2, alumina 51·3, lime 14·0, water 4·5 = 100.

Pyr., etc.—Yields water in the closed tube. B.B. whitens and fuses on the edges. Slowly and imperfectly decomposed by boiling hydrochloric acid.

Obs.—Associated commonly with corundum, and in many cases obviously formed directly from it; thus at the emery deposits of Gumuch-dagh in Asia Minor, the islands Naxos, Nicaria, etc. Occurs in chlorite of Mt. Greiner, Sterzing, Tyrol. In the U. S., at the emery mine at Chester, Mass.; at Unionville, Chester Co., Pa.; with corundum in

Madison Co. and elsewhere in North Carolina; at Gainesville, Hall Co., Georgia; at Dudleyville, Alabama.

Named *Margarite* from *μαργαρίτης*, *pearl*.

SEYBERTITE. Clintonite. Brandisite.

Monoclinic, near biotite in form. Also foliated massive; sometimes lamellar radiate.

Cleavage: basal, perfect. Structure foliated, micaceous. Laminæ brittle. Percussion- and pressure-figures, as with mica. H. = 4–5. G. = 3–3·1. Luster pearly submetallic. Color reddish brown, yellowish, copper-red. Streak uncolored, or slightly yellowish or grayish. Pleochroism rather feeble. Optically —. Ax. pl. $\perp b$ *seybertite;* $\parallel b$ *brandisite.* Bx_a nearly $\perp c$. Axial angles variable, but not large. Birefringence high.

Var.—1. The Amity *seybertite* (*clintonite*) is in reddish-brown to copper-red brittle foliated masses; the surfaces of the folia often marked with equilateral triangles like some mica and chlorite. Axial angle 3°–13°.

2. *Brandisite* (*disterrite*), from the Fassathal, Tyrol, is in hexagonal prisms of a yellowish-green or leek-green color to reddish gray; H. = 5 of base; of sides, 6–6·5. Ax. plane $\parallel b$. Axial angle 15°–30°. Some of it pseudomorphous, after fassaite.

Comp.—In part $H_3(Mg,Ca)_5Al_5Si_2O_{18} = 3H_2O.10(Mg,Ca)O.5Al_2O_3.4SiO_2$.

Pyr., etc.—Yields water. B.B. infusible alone, but whitens. In powder acted on by concentrated acids.

Obs.—*Seybertite* occurs at Amity, N. Y., in limestone with serpentine, associated with amphibole, spinel, pyroxene, graphite, etc.; also a chlorite near leuchtenbergite. *Brandisite* occurs on Mt. Monzoni in the Fassathal, Tyrol, in white limestone, with fassaite and black spinel.

Xanthophyllite. Perhaps $H_8(Mg,Ca)_{14}Al_{16}Si_5O_{52}$. The original *xanthophyllite* is in crusts or in implanted globular forms. Optically negative. Ax. angle usually very small, or sensibly uniaxial; sometimes 20°. From near Zlatoust in the Ural.

Walueweite is the same species occurring in distinct pseudo-rhombohedral crystals. Folia brittle. H. = 4·6. G. = 3·093. Luster vitreous; on cleavage plane pearly. Color leek- to bottle-green. Transparent to translucent. Pleochroism rather feeble: $\parallel \dot{c}$ fine green; $\perp \dot{c}$ reddish brown. Optically —. Ax. pl. $\parallel b$. Bx sensibly $\perp c$. 2E = 20°–40°. Axial angle 17° to 32°. Found with perovskite and other species in chloritic schists near Achmatovsk, in the southern Ural.

CHLORITOID. Chloritspath. Ottrelite. Phyllite.

Probably triclinic. Rarely in distinct tabular crystals, usually hexagonal in outline, often twinned with the individuals turned in azimuth 120° to each other. Crystals grouped in rosettes. Usually coarsely foliated massive; folia often curved or bent; and brittle; also in thin scales or small plates disseminated through the containing rock.

Cleavage: basal, but less perfect than with the micas; also imperfect parallel to planes inclined to the base nearly 90° and to each other about 60°; *b* difficult. Laminæ brittle. H. = 6·5. G. = 3·52–3·57. Color dark gray, greenish gray, greenish black, grayish black, often grass-green in very thin plates. Streak uncolored, or grayish, or very slightly greenish. Luster of surface of cleavage somewhat pearly.

Pleochroism strong: $\mathfrak{c}$ yellow-green, $\mathfrak{b}$ indigo-blue, $\mathfrak{a}$ olive-green. Optically +. Ax. pl. nearly $\parallel b$. Bx_a inclined about 12° or more to the normal to *c* (001). Dispersion $\rho > v$, large, also horizontal. Axial angles large, in air 100° to 118°. Birefringence low, $\gamma - \alpha = 0·015$.

Comp.—For chloritoid $H_2(Fe.Mg)Al_2SiO_7$. If iron alone is present, this requires: Silica 23·8, alumina 40·5, iron protoxide 28·5, water 7·2 = 100.

Diff.—Recognized by the crystal outlines and general micaceous appearance; high relief; green colors; distinct cleavage; frequent twinning; strong pleochroism and low interference-colors. By the last character readily distinguished from the micas; also by the high relief and extinction oblique to the cleavage from the chlorites.

Obs.—Chloritoid (ottrelite, etc.) are characteristic of sedimentary rocks which have suffered dynamic metamorphism, especially in the earlier stages; thus found in argillites, conglomerates, etc., which have assumed the schistose condition. With more advanced degree of metamorphism it disappears. Often grouped in fan-shaped, sheaf-like forms, also in irregular or rounded grains.

The original *chloritoid* from Kosoibrod, near Ekaterinburg in the Ural, is in large curving laminæ or plates, grayish to blackish green in color, often spotted with yellow from mixture with limonite. Other localities are Ile le Groix (Morbihan); embedded in large crystals at Vaulup, Shetland; Ardennes in schists with ottrelite; also from Upper Michigan; Leeds, Canada, etc.

Sismondine ($H_{14}Fe_7Al_{16}Si_8O_{54}$) is from St. Marcel; it occurs also with glaucophane at Zermatt in the Valais, Switzerland, and elsewhere.

Salmite is a manganesian variety occurring in irregular masses, having a coarse saccharoidal structure and grayish color. G. = 3·38. From Vielsalm, Belgium.

Masonite, from Natic, R. I., is in very broad plates of a dark grayish-green color, but bluish green in very thin laminæ parallel to *c*, and grayish green at right angles to this; occurs in argillaceous schist.

Ottrelite is generally classed with chloritoid, though it is not certain that they are identical; it seems to have the composition $H_2(Fe,Mn)Al_2Si_2O_9$. It occurs in small, oblong, shining scales or plates, more or less hexagonal in form and gray to black in color; in argillaceous schist near Ottrez, on the borders of Luxembourg, and from the Ardennes; also near Serravezza, Tuscany; Tintagel in Cornwall. *Venasquite* is from Venasque in the Pyrenees, and from Teulé, Finistère. *Phyllite* is from the schists of New England.

---

3. Chlorite Group. Monoclinic.

The CHLORITE GROUP takes its name from the fact that a large part of the minerals included in it are characterized by the *green* color common with silicates in which ferrous iron is prominent. The species are in many respects closely related to the micas. They crystallize in the monoclinic system, but in part with distinct monoclinic symmetry, in part with rhombohedral symmetry, with corresponding uniaxial optical character. The plane angles of the base are also 60° or 120°, marking the mutual inclinations of the chief zones of forms. The mica-like basal cleavage is prominent in distinctly crystallized forms, but the laminæ are tough and comparatively inelastic. Percussion- and pressure-figures may be obtained as with the micas and have the same orientation. The etching-figures are in general monoclinic in symmetry, in part also asymmetric, suggesting a reference to the triclinic system.

Chemically considered the chlorites are silicates of aluminium with ferrous iron and magnesium and chemically combined water. Ferric iron may be present replacing the aluminium in small amount; chromium enters similarly in some forms, which are then usually of a pink instead of the more common green color. Manganese replaces the ferrous iron in a few cases. Calcium and alkalies—characteristic of all the true micas—are conspicuously absent, or present only in small amount.

The only distinctly crystallized species of the Chlorite Group are Clinochlore and Penninite. These seem to have the same composition, but while the former is monoclinic in form and habit, the latter is pseudo-rhombohedral and usually uniaxial. Prochlorite (including some ripidolite) and Corundophilite also occur in distinct cleavage masses.

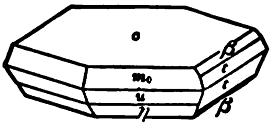
Besides the species named there are other kinds less distinct in form, occurring in scales, also fibrous to massive or earthy; they are often of more or less undetermined composition, but in many cases, because of their extensive occurrence, of considerable geological importance. These latter forms occur as secondary minerals resulting from the alteration especially of ferro-magnesian silicates, such as biotite, pyroxene, amphibole; also garnet, vesuvianite, etc. They are often accompanied by other secondary minerals, as serpentine, limonite, calcite, etc., especially in the altered forms of basic rocks.

The rock-making chlorites are recognized in thin sections by their characteristic appearance in thin leaves, scales or fibers, sometimes aggregated into spherulites; by their greenish color; pleochroism; extinction parallel to the cleavage (unlike chloritoid and ottrelite); low relief and extremely low interference-colors, which frequently exhibit the "ultra-blue." By this latter character they are readily distinguished from the micas, which they strongly resemble and with which they are frequently associated.

CLINOCHLORE. Ripidolite *pt.*

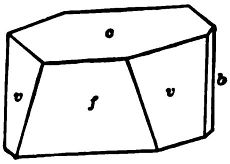
Monoclinic. Axes: $\grave{a} : \bar{b} : \grave{c} = 0·57735 : 1 : 2·2772$; $\beta = 89° 40'$.

908.



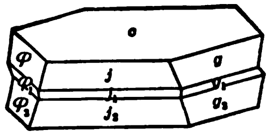
Pfitsch.

909.



Schwarzenstein.

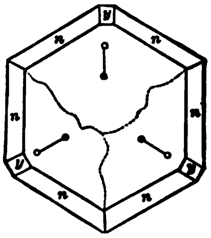
910.



Zillerthal.

Crystals usually hexagonal in form, often tabular ∥ c. Plane angles of the basal section = 60° or 120°, and since closely similar angles are found in the zones which are separated by 60°, the symmetry approximates to that of the rhombohedral system.

911.



Achmatovsk.

Twins: (1) *Mica law*, tw. pl. $\perp c$ in the zone cm_0; sometimes contact-twins with c as comp.-face, the one part revolved 60° or a multiple of 60° in azimuth with reference to the other; also in threefold twins. (2) *Penninite law*, tw. pl. c, contact-twins also united by c (Fig. 910); here corresponding faces differ 180° in position. Massive, coarse scaly granular to fine granular and earthy.

Cleavage: c highly perfect. Laminæ flexible tough, and but slightly elastic. Percussion-figure and pressure-figures orientated as with the micas (p. 464). H. = 2–2·5. G. = 2·65–2·78. Luster of cleavage-face somewhat pearly. Color deep grass-green to olive-green; pale green to yellowish and white; also rose-red. Streak greenish white to uncolored. Transparent to translucent. Pleochroism not strong, for green varieties usually $\mathfrak{a}$ green, $\mathfrak{c}$ yellow. Optically usually +. Ax. pl. in most cases ∥ b. Bx_a inclined somewhat to the normal to c, forward; for Achmatovsk 2° 30′. Dispersion $\rho < v$. Axial angles variable, even in the same crystal, $2E = 20°–90°$; sometimes sensibly uniaxial. Birefringence low. $\beta = 1·588$; $\gamma - \alpha = 0·011$.

Var.—1. *Ordinary;* green clinochlore, passing into bluish green; (*a*) in crystals, as described, usually with distinct monoclinic symmetry; (*b*) foliated; (*c*) massive.

Leuchtenbergite. Contains usually little or no iron. Color white, pale green, yellowish; often resembles talc. From near Zlatoust in the Ural.

Kotschubeite. Contains several per cent of chromium oxide. Crystals rhombohedral in habit. Color rose-red. From the southern Ural.

Manganiferous. Manganchlorite. A chlorite from the Harstig mine near Pajsberg, Sweden, is peculiar in containing 2·3 p. c. MnO.

Comp.—Normally $H_8Mg_5Al_2Si_3O_{18} = 4H_2O.5MgO.Al_2O_3.3SiO_2$ = Silica 32·5, alumina 18·4, magnesia 36·1, water 13·0 = 100. Ferrous iron usually replaces a small part of the magnesia, and the same is true of manganese rarely; sometimes chromium replaces the aluminium.

Pyr., etc.—Yields water. B.B. in the platinum forceps whitens and fuses with difficulty on the edges to a grayish-black glass. With borax, a clear glass colored by iron, and sometimes chromium. In sulphuric acid wholly decomposed.

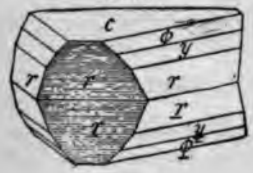
Obs.—Occurs in connection with chloritic and talcose rocks or schists and serpentine; sometimes in parallel position with biotite or phlogopite. Prominent localities are: Achmatovsk in the Ural; Ala in Piedmont; the Zillerthal; Zermatt, Switzerland; Marienberg, Saxony; Zöptau, Moravia. A manganesian variety occurs at Pajsberg, Sweden.

In the U. States, at Westchester, Penn., in large crystals and plates; also Unionville and Texas, Penn.; at the magnetic iron mine at Brewster, N. Y., in part changed to serpentine.

PENNINITE. Pennine.

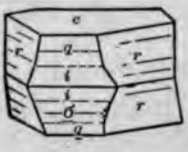
Apparently rhombohedral in form but strictly pseudo-rhombohedral and monoclinic.

912.



Texas.

913.



Zermatt.

Habit rhombohedral: sometimes thick tabular with *c* prominent, again steep rhombohedral; also in tapering six-sided pyramids. Rhombohedral faces often horizontally striated. Crystals often in crested groups. Also massive, consisting of an aggregation of scales; also compact cryptocrystalline.

Cleavage: *c* highly perfect. Laminæ flexible. Percussion-figure and pressure-figure as with clinochlore but less easy to obtain; not elastic. H. = 2–2·5. G. = 2·6–2·85. Luster of cleavage-surface pearly; of lateral plates vitreous, and sometimes brilliant. Color emerald- to olive-green; also violet, pink, rose-red, grayish red; occasionally yellowish and silver-white. Transparent to subtranslucent. Pleochroism distinct: usually ∥ *c* green; ⊥ *c* yellow. Optically +, also −, and sometimes both in adjacent laminæ of the same crystal. Usually sensibly uniaxial, but sometimes distinctly biaxial (occasionally 2E = 61°) and both in the same section. Sometimes a uniaxial nucleus while the border is biaxial with 2E = 36°, the latter probably to be referred to clinochlore. Indices 1·576 and 1·579 Lévy-Lcx.

Var.—1. *Penninite*, as first named, included a green crystallized chlorite from the Penninine Alps.

Kämmererite. In hexagonal forms bounded by steep six-sided pyramids. Color kermes-red; peach-blossom-red. Pleochroism distinct. Optically − from L. Itkul, Bisersk, Perm, Russia; + Texas, Pa. Uniaxial or biaxial with axial angle up to 20°. Rhodophyllite from Texas, Pa., and rhodochrome from L. Itkul belong here.

Pseudophite is compact massive, without cleavage, and resembles serpentine.

Comp.—Essentially the same as clinochlore, $H_8(Mg,Fe)_5Al_2Si_3O_{18}$.

Pyr., etc.—In the closed tube yields water. B.B. exfoliates somewhat and is difficultly fusible. With the fluxes all varieties give reactions for iron, and many varieties react for chromium. Partially decomposed by hydrochloric and completely by sulphuric acid.

Obs.—Occurs with serpentine in the region of Zermatt, Valais, near Mt. Rosa, especially in the moraines of the Findelen glacier; crystals from Zermatt are sometimes 2 in. long and 1¼ in. thick; also at the foot of the Simplon; at Ala, Piedmont, with clinochlore; at Schwarzenstein in Tyrol; at Taberg in Wermland; at Snarum, greenish and foliated.

Kämmererite is found at the localities already mentioned; also near Miask in the Ural;

at Haroldswick in Unst, Shetland Isles. In large crystals enclosed in the talc in crevices of the chromite from Kraubat, Styria. Abundant at Texas, Lancaster Co., Pa., along with clinochlore, some crystals being embedded in clinochlore, or the reverse. Also in N. Carolina, with chromite at Culsagee, Macon Co.; Webster, Jackson Co.; and other points.

PROCHLORITE. Ripidolite pt.

Monoclinic. In six-sided tables or prisms, the side planes strongly furrowed and dull. Crystals often implanted by their sides, and in divergent groups, fan-shaped, vermicular, or spheroidal. Also in large folia. Massive, foliated, or granular.

H. = 1–2. G. = 2·78–2·96. Translucent to opaque; transparent only in very thin folia. Luster of cleavage surface feebly pearly. Color green, grass-green, olive-green, blackish green; across the axis by transmitted light sometimes red. Streak uncolored or greenish. Laminæ flexible, not elastic. Pleochroism distinct. Optically + in most cases. Bx inclined to the normal to c some 2°. Axial angle small, often nearly uniaxial; again 2E = 23°—30°. Dispersion $\rho < v$.

Comp.—Lower in silicon than clinochlore, and with ferrous iron usually, but not always, in large amount. Analysis by Egger:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	
Zillerthal	26·02	20·16	1·07	28·08	15·50	0·44	9·65	= 100·92

Obs.—Like other chlorites in modes of occurrence. Sometimes in implanted crystals, as at St. Gothard, enveloping often adularia, etc.; Mt. Greiner in the Zillerthal, Tyrol; Rauris in Salzburg; Traversella in Piedmont; at Mtn. Sept Lacs and St. Cristophe in Dauphiné; in Styria, Bohemia. Also massive in Cornwall, in tin veins; at Arendal in Norway; Salberg and Dannemora, Sweden; Dognacska, Hungary. Occasionally formed from amphibole. In Scotland at various points. In the U. States, near Washington; on Castle Mt., Batesville, Va., a massive form resembling soapstone, color grayish green, feel greasy; Steele's mine, Montgomery Co., N. C.; also with corundum at the Culsagee mine, in broad plates of a dark green color and fine scaly; it differs from ordinary prochlorite in the small amount of ferrous iron.

Corundophilite. A chlorite occurring in deep green laminæ resembling clinochlore but more brittle; contains but 24 p. c. SiO_2. Occurs with corundum at Chester, Mass.

AMESITE. $H_4(Mg,Fe)_2Al_2SiO_9$. Silica 21·4 p. c. In hexagonal plates, foliated, resembling the green talc from the Tyrol. H. = 2·5–3. G. = 2·71. Color apple-green. Luster pearly on cleavage face. Optically +, sensibly uniaxial. Occurs with diaspore at Chester, Mass.

OTHER CHLORITES. Besides the chlorites already described which occur usually in distinct crystals or plates, there are, as noted on p. 472, forms varying from fine scaly to fibrous and earthy, which as already noted are prominent in rocks. In some cases they may belong to the species before described, but frequently the want of sufficient pure material has left their composition in doubt. These chlorites are commonly characterized by their green color, distinct pleochroism and low birefringence (p. 473).

The following are names which have been given particularly to the chlorites filling cavities or seams in basic igneous rocks: *aphrosiderite, diabantite, delessite, epichlorite, euralite, chlorophæite, hullite.*

The following are other related minerals.

Cronstedtite. $4FeO.2Fe_2O_3.3SiO_2.4H_2O$. Occurs tapering in hexagonal pyramids; also in diverging groups; amorphous. Cleavage: basal, highly perfect. Thin laminæ elastic. G. = 3·34–3·35. Color coal-black to brownish black; by transmitted light in thin scales emerald-green. Streak dark olive-green. From Přibram in Bohemia; also in Cornwall.

Thuringite. $8FeO.4(Al,Fe)_2O_3.6SiO_2.9H_2O$. Massive; an aggregation of minute pearly scales. Color olive-green to pistachio-green. From near Saalfeld, in Thuringia; Hot Springs, Arkansas, etc.; from the metamorphic rocks on the Potomac, near Harper's Ferry (*owenite*).

Chamosite. Contains iron (FeO) with but little MgO. Occurs compact or oölitic, with H. about 3; G. = 3–3·4; color greenish gray to black. From Chamoson, near St. Maurice, in the Valais.

Stilpnomelane. An iron silicate. In foliated plates; also fibrous, or as a velvety coating. G. = 2·77–2·96. Color black, greenish black. Occurs at Obergrund and elsewhere in Silesia; also in Moravia; near Weilburg, Nassau. *Chalcodite*, from the Sterling Iron mine, in Antwerp, Jefferson Co., N. Y., coating hematite and calcite, is the same mineral in velvety coating of mica-like scales with a bronze color.

Strigovite. $H_4Fe_2(Al,Fe)_2Si_2O$. In aggregations of minute crystals. Color dark green. Occurs as a fine coating over the minerals in cavities in the granite of Striegau in Silesia.

Rumpfite. $H_{28}Mg_7Al_{16}Si_{10}O_{66}$. Massive; granular, consisting of very fine scales. Color greenish white. Occurs with talc near St. Michael in Upper Styria.

APPENDIX TO THE MICA DIVISION.—VERMICULITES.

The **Vermiculite Group** includes a number of micaceous minerals, all hydrated silicates, in part closely related to the chlorites, but varying somewhat widely in composition. They are alteration-products chiefly of the micas, biotite, phlogopite, etc., and retain more or less perfectly the micaceous cleavage, and often show the negative optical character and small axial angle of the original species. Many of them are of a more or less indefinite chemical nature, and the composition varies with that of the original mineral and with the degree of alteration.

The laminæ in general are soft, pliable, and inelastic; the luster pearly or bronze-like, and the color varies from white to yellow and brown. Heated to 100°–110° or dried over sulphuric acid most of the vermiculites lose considerable water, up to 10 p. c., which is probably hygroscopic; at 300° another portion is often given off; and at a red heat a somewhat larger amount is expelled. Connected with the loss of water upon ignition is the common physical character of exfoliation; some of the kinds especially show this to a marked degree, slowly opening out, when heated gradually, into long worm-like threads. This character has given the name to the group, from the Latin *vermiculari, to breed worms*. The minerals included can hardly rank as distinct species and only their names can be given here: *Jefferisite*, *vermiculite*, *culsageeite*, *kerrite*, *lennilite*, *hallite*, *philadelphite*, *vaalite*, *maconite*, *dudleyite*, *pyrosclerite*.

III. Serpentine and Talc Division.

The leading species belonging here, Serpentine and Talc, are closely related to the Chlorite Group of the Mica Division preceding, as noted beyond. Some other magnesium silicates, in part amorphous, are included with them.

SERPENTINE.

Monoclinic. In distinct crystals, but only as pseudomorphs. Sometimes foliated, folia rarely separable; also delicately fibrous, the fibers often easily separable, and either flexible or brittle. Usually massive, but microscopically finely fibrous and felted, also fine granular to impalpable or cryptocrystalline; slaty. Crystalline in structure but often by compensation nearly isotropic; amorphous.

Cleavage *b* (010), sometimes distinct; also prismatic (50°) in chrysotile. Fracture usually conchoidal or splintery. Feel smooth, sometimes greasy. H. = 2·5–4, rarely 5·5. G. = 2·50–2·65; some fibrous varieties 2·2–2·3; retinalite, 2·36–2·55. Luster subresinous to greasy, pearly, earthy; resin-like, or wax-like; usually feeble. Color leek-green, blackish green; oil- and siskin-green; brownish red, brownish yellow; none bright; sometimes nearly white. On exposure, often becoming yellowish gray. Streak white, slightly shining. Translucent to opaque.

Pleochroism feeble. Optically −, perhaps also + in chrysotile. Double refraction weak. Ax. pl. ∥ *a* (100). Bx (a) ⊥ *b* (010) the cleavage surface; c ∥ elongation of fibers. Biaxial, angle variable, often large; 2V = 20° to 90°. Indices:

Antigorite $\alpha = 1{\cdot}560$ $\beta = 1{\cdot}570$ $\gamma = 1{\cdot}571$ $\gamma - \alpha = 0{\cdot}011$ Lévy-Lcx.

Var.—Many unsustained species have been made out of serpentine, differing in structure (massive, slaty, foliated, fibrous), or, as supposed, in chemical composition; and these now, in part, stand as varieties, along with some others based on variations in texture, etc.

A. IN CRYSTALS—PSEUDOMORPHS. The most common have the form of chrysolite. Other kinds are pseudomorphs after pyroxene, amphibole, spinel, chondrodite, garnet, phlogopite, etc. *Bastite* or *Schiller Spar* is enstatite (hypersthene) altered more or less completely to serpentine. See p. 386.

B. MASSIVE. 1. *Ordinary massive.* (*a*) *Precious* or *Noble Serpentine* is of a rich oil-green color, of pale or dark shades, and translucent even when in thick pieces. (*b*) *Common Serpentine* is of dark shades of color, and subtranslucent. The former has a hardness of 2·5–3; the latter often of 4 or beyond, owing to impurities.

Resinous. Retinalite. Massive, honey-yellow to light oil green, waxy or resin-like luster.

Bowenite (Nephrite *Bowen*). Massive, of very fine granular texture, and much resembles nephrite, and was long so called. It is apple-green or greenish white in color; G. = 2·594–2·787, Bowen; and it has the unusual hardness 5·5–6. From Smithfield, R. I.; also a similar kind from New Zealand.

C. LAMELLAR. *Antigorite*, thin lamellar in structure, separating into translucent folia; H. = 2·5; G = 2·622; color brownish green by reflected light; feel smooth, but not greasy. From Antigorio valley, Piedmont.

D. THIN FOLIATED. *Marmolite*, thin foliated; the laminæ brittle but separable. G. = 2·41; colors greenish white, bluish white to pale asparagus-green. From Hoboken, N. J.

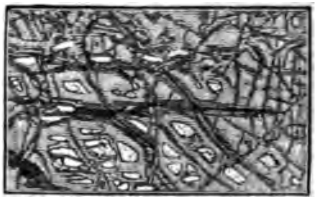
E. FIBROUS. *Chrysotile.* Delicately fibrous, the fibers usually flexible and easily separating; luster silky, or silky metallic; color greenish white, green, olive-green, yellow and brownish; G. = 2·219. Often constitutes seams in serpentine. It includes most of the silky *amianthus* of serpentine rocks and much of what is popularly called *asbestus* (asbestos). Cf. p. 401.

Picrolite, columnar, but fibers or columns not easily flexible, and often not easily separable, or affording only a splintery fracture; color dark green to mountain-green, gray, brown. The original was from Taberg, Sweden. *Baltimorite* is picrolite from Bare Hills, Md.

F. SERPENTINE ROCKS. Serpentine often constitutes rock-masses. It frequently occurs mixed with more or less of dolomite, magnesite, or calcite, making a rock of clouded green, sometimes veined with white or pale green, called *verd antique*, *ophiolite*, or *ophicalcite*. Serpentine rock is sometimes mottled with red, or has something of the aspect of a red porphyry; the reddish portions containing an unusual amount of oxide of iron. Any serpentine rock cut into slabs and polished is called *serpentine marble*.

Microscopic examination has established the fact that serpentine in rock-masses has been largely produced by the alteration of chrysolite, and many apparently homogeneous serpentines show more or less of this original mineral. In other cases it has resulted from the alteration of pyroxene or amphibole. Sections of the serpentine derived from chrysolite often show a peculiar structure, like the meshes of a net (Fig. 914); the lines marked by grains of magnetite also follow the original cracks and cleavage directions of the chrysolite (Fig. 915, *a*). The serpentine from amphibole and pyroxene commonly shows an analogous structure; the iron particles following the former cleavage lines Hence the nature of the original mineral can often be inferred. Cf. Fig. 915, *a*, *b*, *c* (Pirsson).

914.



Comp.—A magnesium silicate, $H_4Mg_3Si_2O_9$ or $3MgO.2SiO_2.2H_2O$ = Silica 44·1, magnesia 43·0, water 12·9 = 100. Iron protoxide often replaces a small part of the magnesium; nickel in small amount is sometimes present. The water is chiefly expelled at a red heat.

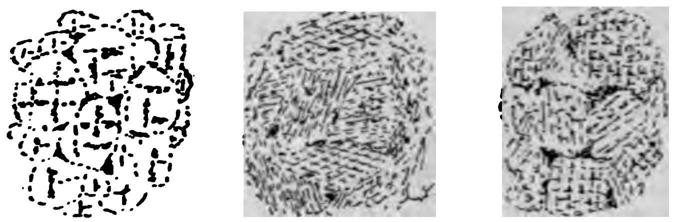
Pyr., etc.—In the closed tube yields water. B.B. fuses on the edges with difficulty.

F. = 6. Gives usually an iron reaction. Decomposed by hydrochloric and sulphuric acids. From chrysotile the silica is left in fine fibers.

Diff.—Characterized by softness, absence of cleavage and feeble waxy or oily luster; low specific gravity; by yielding much water B.B.

Readily recognized in thin sections by its greenish or yellowish-green color; low relief and aggregate polarization due to its fibrous structure. When the fibers are parallel, the interference-colors are not very low, but the confused aggregates may show the "ultra blue" or even be isotropic. The constant association with other magnesia bearing minerals like chrysolite, pyroxene, hornblende, etc., is also characteristic. The presence of lines of iron particles as noted above (Fig. 915) is characteristic.

915.



a, Serpentine derived from chrysolite; *b*, from amphibole; *c*, from pyroxene.

Obs.—Serpentine is always a secondary mineral resulting, as noted above, from the alteration of silicates containing magnesia, particularly chrysolite, amphibole or pyroxene. It frequently forms large rock-masses, then being derived from the alteration of peridotites, dunites and other basic rocks of igneous origin; also of amphibolites, or pyroxene and chrysolite rocks of metamorphic origin. In the first case it is usually accompanied by spinel, garnet, chromite and sometimes nickel ores; in the second case by various carbonates such as dolomite, magnesite, breunnerite, etc.

Crystals of serpentine, pseudomorphous after monticellite, occur in the Fassathal, Tyrol; near Miask at Lake Aushkul, Barsovka, Ekaterinburg, and elsewhere; in Norway, at Snarum; etc. Fine precious serpentines come from Falun and Gulsjö in Sweden, the Isle of Man, the neighborhood of Portsoy in Aberdeenshire, the Lizard in Cornwall, Corsica, Siberia, Saxony, etc.

In N. America, in *Maine*, at Deer Isle, precious serpentine. In *Vermont*, at New Fane, Roxbury, etc. In *Mass.*, fine at Newburyport. In *R. Island*, at Newport; *bowenite* at Smithfield. In *Conn.*, near New Haven and Milford, at the verd-antique quarries. In *N. York*, at Port Henry, Essex Co.; at Antwerp, Jefferson Co., in crystals; in Gouverneur, St. Lawrence Co., in crystals; in Cornwall. Monroe, and Warwick, Orange Co., sometimes in large crystals at Warwick; and from Richmond to New Brighton, Richmond Co. In *N. Jersey*, at Hoboken, with brucite, magnesite, etc.; at Montville, Morris Co., chrysotile and retinalite, with common serpentine, produced by the alteration of pyroxene. In *Penn.*, massive, fibrous, and foliated, at Texas, Lancaster Co.; at West Chester, Chester Co., *williamsite;* at Mineral Hill, Newtown, Marple, and Middletown, Delaware Co. In *Maryland*, at Bare Hills; at Cooptown, Harford Co., with diallage. In *California*, at various points in the Coast Range.

In *Canada*, abundant among the metamorphic rocks of the Eastern Townships and Gaspé peninsula, Quebec; at Thetford, Coleraine, Broughton, Orford, S. Ham, Bolton, Shipton, Melbourne, etc. The fibrous variety chrysotile (asbestus, bostonite) often forms seams several inches in thickness in the massive mineral, and is now extensively mined for technical purposes. Massive Laurentian serpentine also occurs in Grenville, Argenteuil Co., Quebec, and North Burgess, Lanark Co., Ontario. In *N. Brunswick*, at Crow's Nest in Portland.

The names *Serpentine*, *Ophite*, *Lapis colubrinus*, allude to the green serpent-like cloudings of the serpentine marble. *Retinalite* is from ῥετινή, *resin; Picrolite*, from πικρός, *bitter*, in allusion to the magnesia (or Bittererde) present; *Thermophyllite*, from θέρμη, *heat*, and φύλλον, *leaf*, on account of the exfoliation when heated; *Chrysotile*, from χρυσος, *golden*, and τίλος, *fibrous; Metaxite*, from μέταξα, *silk; Marmolite*, from μαρμαίρω, *to shine*, in allusion to its peculiar luster.

Deweylite. A magnesian silicate near serpentine but with more water. Formula perhaps $4MgO.3SiO_2.6H_2O$. Amorphous, resembling gum arabic, or a resin. H. = 2–3·5. G. = 2·0–2·2 Color whitish, yellowish, reddish, brownish. Occurs with serpentine in the Fleimsthal, Tyrol; also at Texas, Penn., and the Bare Hills, Md. *Gymnite* of Thomson, named from γυμνός, *naked*, in allusion to the locality at Bare Hills, Md., is the same species.

Genthite. Nickel Gymnite. A gymnite with part of the magnesium replaced by nickel, $2NiO.2MgO.3SiO_2.6H_2O$. Amorphous, with a delicate stalactitic surface, incrusting. H. = 3–4; sometimes very soft. G. = 2·409. Luster resinous. Color pale apple-green, or yellowish. From Texas, Lancaster Co., Pa., in thin crusts on chromite.

Garnierite. Noumeite. An important ore of nickel, consisting essentially of a hydrated silicate of magnesium and nickel, perhaps $H_2(Ni,Mg)SiO_4 + aq$, but very variable in composition, particularly as regards the nickel and magnesium; not always homogeneous. Amorphous. Soft and friable. G. = 2·3–2·8. Luster dull. Color bright apple-green, pale green to nearly white. In part unctuous; sometimes adheres to the tongue. Occurs in serpentine rock near Noumea, capital of New Caledonia, associated with chromic iron and steatite, where it is extensively mined. A similar ore occurs at Riddle in Douglas County, southern Oregon; also at Webster, Jackson Co., N. C.

TALC.

Orthorhombic or monoclinic. Rarely in tabular crystals, hexagonal or rhombic with prismatic angle of 60°. Usually foliated massive; sometimes in globular and stellated groups; also granular massive, coarse or fine; fibrous (pseudomorphous); also compact or cryptocrystalline.

Cleavage: basal, perfect. Sectile. Flexible in thin laminæ, but not elastic. Percussion-figure a six-rayed star, oriented as with the micas. Feel greasy. H. = 1–1·5. G. = 2·7–2·8. Luster pearly on cleavage surface. Color apple-green to white, or silvery-white; also greenish gray and dark green; sometimes bright green perpendicular to cleavage surface, and brown and less translucent at right angles to this direction; brownish to blackish green and reddish when impure. Streak usually white; of dark green varieties lighter than the color. Subtransparent to translucent. Optically negative. Ax. pl. $\parallel a$. Bx $\perp c$. Axial angle small. $\gamma - \alpha = 0·035–0·050$.

Var.—*Foliated, Talc.* Consists of folia, usually easily separated, having a greasy feel, and presenting ordinarily light green, greenish white, and white colors. G. = 2·55–2·78.

Massive, Steatite or *Soapstone* (Speckstein *Germ.*). *a.* Coarse granular, grayish green, and brownish gray in color; H. = 1–2·5. *Pot-stone* is ordinary soapstone, more or less impure. *b.* Fine granular or cryptocrystalline, and soft enough to be used as chalk; as the *French chalk*, which is milk-white with a pearly luster. *c. Indurated talc.* An impure slaty talc, harder than ordinary talc.

Pseudomorphous. a. Fibrous, fine to coarse, altered from enstatite and tremolite. *b. Rensselaerite*, having the form of pyroxene from northern New York and Canada.

Comp.—An acid metasilicate of magnesium, $H_2Mg_3(SiO_3)_4$, or $H_2O.3MgO.4SiO_2$ = Silica 63·5, magnesia 31·7, water 4·8 = 100. The water goes off only at a red heat. Nickel is sometimes present in small amount.

Pyr., etc.—In the closed tube B.B., when intensely ignited, most varieties yield water. In the platinum forceps whitens, exfoliates, and fuses with difficulty on the thin edges to a white enamel. Moistened with cobalt solution, assumes on ignition a pale red color. Not decomposed by acids. Rensselaerite is decomposed by concentrated sulphuric acid.

Diff.—Characterized by extreme softness, soapy feel; common foliated structure; pearly luster; it is flexible but inelastic. Yields water only on intense ignition.

Obs.—Talc or steatite is a very common mineral, and in the latter form constitutes extensive beds in some regions. It is often associated with serpentine, talcose or chloritic schist, and dolomite, and frequently contains crystals of dolomite, breunnerite, also asbestus, actinolite, tourmaline, magnetite.

Steatite is the material of many pseudomorphs, among which the most common are those after pyroxene, hornblende, mica, scapolite, and spinel. The magnesian minerals are

those which commonly afford steatite by alteration; while those like scapolite and nephelite, which contain soda and no magnesia, most frequently yield pinite-like pseudomorphs. There are also steatitic pseudomorphs after quartz, dolomite, topaz, chiastolite, staurolite, cyanite, garnet, vesuvianite, chrysolite, gehlenite. Talc in the fibrous form is pseudomorph after enstatite and tremolite.

Apple-green talc occurs at Mt. Greiner in the Zillerthal, Tyrol; in the Valais and St. Gothard in Switzerland; in Cornwall, near Lizard Point, with serpentine; the Shetland islands.

In N. America, foliated talc occurs in *Maine*, at Dexter. In *Vermont*, at Bridgewater, handsome green talc, with dolomite; Newfane. In *Mass.*, at Middlefield, Windsor, Blandford, Andover, and Chester. In *R. Island*, at Smithfield, delicate green and white in a crystalline limestone. In *N. York*, at Edwards, St. Lawrence Co., a fine fibrous talc (*agalite*) associated with pink tremolite; on Staten Island. In *N. Jersey*, Sparta. In *Penn.*, at Texas, Nottingham, Unionville; in South Mountain, ten miles south of Carlisle; at Chestnut Hill, on the Schuylkill, talc and also soapstone, the latter quarried extensively. In *Maryland*, at Cooptown, of green, blue, and rose colors. In *N. Car.*, at Webster, Jackson Co. In *Canada*, in the townships Bolton, Sutton, and Potton, Quebec, with steatite in beds of Cambrian age; in the township of Elzevir, Hastings Co., Ontario, an impure grayish var. in Archæan rocks.

SEPIOLITE. Meerschaum *Germ.* L'Écume de mer *Fr.*

Compact, with a smooth feel, and fine earthy texture, or clay-like; also rarely fibrous. H. = 2–2·5. G. = 2. Impressible by the nail. In dry masses floats on water. Color grayish white, white, or with a faint yellowish or reddish tinge, bluish green. Opaque.

Comp.—$H_4Mg_2Si_3O_{10}$ or $2H_2O.2MgO.3SiO_2$ = Silica 60·8, magnesia 27·1, water 12·1 = 100. Some analyses show more water ($2H_2O$), which is probably to be regarded as hygroscopic. Copper and nickel may replace part of the magnesium.

Pyr., etc.—In the closed tube yields first hygroscopic moisture, and at a higher temperature gives much water and a burnt smell. B.B. some varieties blacken, then burn white, and fuse with difficulty on the thin edges. With cobalt solution a pink color on ignition. Decomposed by hydrochloric acid with gelatinization.

Obs.—Occurs in Asia Minor, in masses in stratified earthy or alluvial deposits at the plains of Eskihi sher; at Hrubschitz in Moravia; in Morocco, called in French *Pierre de Savon de Maroc;* at Vallecas in Spain, in extensive beds.

A fibrous mineral, having the composition of sepiolite, occurs in Utah.

The word *meerschaum* is German for *sea-froth*, and alludes to its lightness and color. *Sepiolite* Glocker is from *σήπια*, *cuttle-fish*, the bone of which is light and porous; and being also a production of the sea, " deinde *spumam marinam* significabat," says Glocker.

Connarite. A hydrous nickel silicate, perhaps $H_4Ni_2Si_3O_{10}$. In small fragile grains. G. = 2·459–2·619. Color yellowish, green. From Röttis, in Saxon Voigtland.

Spadaite. Perhaps $5MgO\ 6SiO_2.4H_2O$. Massive, amorphous. Color reddish. From Capo di Bove, near Rome.

SAPONITE. Piotine.

Massive. In nodules, or filling cavities. Soft, like butter or cheese, but brittle on drying. G. = 2·24–2·30. Luster greasy. Color white, yellowish, grayish green, bluish, reddish. Does not adhere to the tongue.

Comp.—A hydrous silicate of magnesium and aluminium; but the material is amorphous and probably always impure, and hence analyses give no uniform results. Contains SiO_2 40–45 p. c., Al_2O_3 5–10 p. c., MgO 19–26 p. c., H_2O 19–21 p. c.; also Fe_2O_3, FeO, etc.

Pyr., etc.—B.B. gives out water very readily and blackens; thin splinters fuse with difficulty on the edge. Decomposed by sulphuric acid.

Obs.—Occurs in cavities in basalt, diabase, etc.; also with serpentine. Thus at Lizard Point, Cornwall, in veins in serpentine; at various localities in Scotland, etc.

Saponite is from *sapo, soap;* and piotine from *πιότης, fat.*

Celadonite. A silicate of iron, magnesium and potassium. Earthy or in minute scales. Very soft. Color green. From cavities in amygdaloid at Mte. Baldo near Verona.

Glauconite. Essentially a hydrous silicate of iron and potassium. Amorphous, and resembling earthy chlorite; either in cavities in rocks, or loosely granular massive. Color dull green. Abundant in the "green sand," of the Chalk formation, sometimes constituting 75 to 90 p. c. of the whole.

Pholidolite. Corresponds approximately to $5H_2O.K_2O.12(Fe,Mg)O.Al_2O_3.13SiO_2$. In minute crystalline scales. G. = 2·408. Color grayish yellow. From Taberg in Wermland, Sweden, with garnet, diopside, etc.

IV. Kaolin Division.

KAOLINITE. Kaolin.

Monoclinic; in thin rhombic, rhomboidal or hexagonal scales or plates with angles of 60° and 120°. Usually constituting a clay-like mass, either compact, friable or mealy.

Cleavage: basal, perfect. Flexible, inelastic. H. = 2–2·5. G. = 2·6–2·63. Luster of plates, pearly; of mass, pearly to dull earthy. Color white, grayish white, yellowish, sometimes brownish, bluish or reddish. Scales transparent to translucent; usually unctuous and plastic.

Optically biaxial, negative. $Bx_o \perp b$. Bx_a and ax. pl. inclined behind some 20° to normal to *c* (001) Dick. Axial angle large, approx. 90°.

Var.—1. *Kaolinite.* In crystalline scales, pure white and with a satin luster in the mass. 2. *Ordinary.* Common kaolin, in part in crystalline scales but more or less impure including the compact *lithomarge.*

Comp.—$H_4Al_2Si_2O_9$, or $2H_2O.Al_2O_3.2SiO_2$ = Silica 46·5, alumina 39·5, water 14·0 = 100. The water goes off at a high temperature, above 330°.

Pyr., **etc.**—Yields water. B.B. infusible. Gives a blue color with cobalt solution. Insoluble in acids.

Diff.—Characterized by unctuous, soapy feel and the alumina reaction B.B. Resembles infusorial earth, but readily distinguished under the microscope.

Obs.—Ordinary kaolin is a result of the decomposition of aluminous minerals, especially the feldspar of granitic and gneissoid rocks and porphyries. In some regions where these rocks have decomposed on a large scale, the resulting clay remains in vast beds of *kaolin,* usually more or less mixed with free quartz, and sometimes with oxide of iron from some of the other minerals present. Pure kaolinite in scales often occurs in connection with iron ores of the Coal formation. It sometimes forms extensive beds in the Tertiary formation, as near Richmond, Va. Also met with accompanying diaspore and emery or corundum.

Occurs in the coal formation in Belgium; Schlan in Bohemia; in argillaceous schist at Lodève, Dept. of Hérault, France; as kaolin at Diendorf (Bodenmais) in Bavaria; at Schemnitz; with fluor at Zinnwald. Yrieix, near Limoges, is the best locality of kaolin in Europe (a discovery of 1765); it affords material for the famous Sèvres porcelain manufactory. Large quantities of clay (kaolin) are found in Cornwall and West Devon, England.

In the U. States, kaolin occurs at Newcastle and Wilmington, Del.; at various localities in the limonite region of Vermont (at Brandon, etc.), Massachusetts, Pennsylvania; Jacksonville, Ala.; Edgefield, S. C.; near Augusta, Ga.

The name *Kaolin* is a corruption of the Chinese *Kauling,* meaning *high-ridge,* the name of a hill near Jauchau Fu, where the material is obtained.

Pholerite Near kaolinite, but some analyses give 15 p. c. water. The original was from the coal mines of Fins, Dept. of Allier, France.

HALLOYSITE.

Massive. Clay-like or earthy.

Fracture conchoidal. Hardly plastic. H. = 1–2. G. = 2·0–2·20. Luster somewhat pearly, or waxy, to dull. Color white, grayish, greenish, yellowish, bluish, reddish. Translucent to opaque, sometimes becoming translucent or even transparent in water, with an increase of one-fifth in weight.

Var.—*Ordinary*. Earthy or waxy in luster, and opaque massive. *Galapectite* is halloysite of Anglar. *Pseudosteatite* of Thomson & Binney is an impure variety, dark green in color, with H. = 2·25, G. = 2·469. *Indianaite* is a white porcelain clay from Lawrence Co., Indiana, where it occurs with allophane in beds four to ten feet thick.

Smectite is greenish, and in certain states of humidity appears transparent and almost gelatinous; it is from Condé, near Houdan, France.

Bole, in part, may belong here; that is, those colored, unctuous clays containing more or less iron oxide, which also have about 24 p. c. of water; the iron gives them a brownish, yellowish or reddish color; but they may be mixtures. Here belongs *Bergseife* (mountain-soap).

Comp.—A silicate of aluminium ($Al_2O_3.2SiO_2$) like kaolinite, but amorphous and containing more water; the amount is somewhat uncertain, but the formula is probably to be taken as $H_4Al_2Si_2O_9 + aq$, or $2H_2O.Al_2O_3.2SiO_2 + aq$ = Silica 43·5, alumina 36·9, water 19·6 = 100.

Pyr., etc.—Yields water. B.B. infusible. A fine blue with cobalt solution. Decomposed by acids.

Obs.—Occurs often in veins or beds of ore, as a secondary product; also in granite and other rocks, being derived from the decomposition of some aluminous minerals.

Newtonite. $H_8Al_2Si_2O_{11} + aq$. In soft white compact masses resembling kaolin. Found on Sneed's Creek in the northern part of Newton Co., Arkansas.

Cimolite. A hydrous silicate of aluminium, $2Al_2O_3.9SiO_2.6H_2O$. Amorphous, claylike, or chalky. Very soft. G. = 2·18–23·0. Color white, grayish white, reddish. From the island of Argentiera (Kimolos of the Greeks).

Montmorillonite. Probably $H_2Al_2Si_4O_{12} + n$ aq. Massive, clay-like. Very soft and tender. Luster feeble. Color white or grayish to rose-red, and bluish; also pistachio-green. Unctuous. *Montmorillonite*, from Montmorillon, France, is rose-red. *Confolensite* is paler rose-red; fr. Confolens, Dept. of Charente, at St. Jean-de-Côle, near Thiviers.

Stolpenite is a clay from the basalt of Stolpen. *Saponite* of Nicklès is a white, plastic, soap-like clay from the granite from which issues one of the hot springs of Plombières, France, called *Soap Spring;* it was named *smegmatite* by Naumann.

PYROPHYLLITE.

Monoclinic? Foliated, radiated lamellar or somewhat fibrous; also granular to compact or cryptocrystalline; the latter sometimes slaty.

Cleavage: basal, eminent. Laminæ flexible, not elastic. Feel greasy. H. = 1–2. G. = 2·8–2·9. Luster of folia pearly; of massive kinds dull and glistening. Color white, apple-green, grayish and brownish green, yellowish to ocher-yellow, grayish white. Subtransparent to opaque. Optically −. Bx ⊥ cleavage. Ax. angle large, to 108°.

Var.—(1) *Foliated*, and often radiated, closely resembling talc in color, feel, luster and structure. (2) *Compact massive*, white, grayish and greenish, somewhat resembling compact steatite, or French chalk. This compact variety includes part of what has gone under the name of agalmatolite, from China; it is used for slate-pencils, and is sometimes called *pencil-stone*.

Comp.—$H_2Al_2(SiO_3)_4$ or $H_2O.Al_2O_3.4SiO_2$ = Silica 66·7, alumina 28·3, water 5·0 = 100.

Pyr., etc.—Yields water, but only at a high temperature. B.B. whitens, and fuses with difficulty on the edges. The radiated varieties exfoliate in fan-like forms, swelling up to many times the original volume of the assay. Heated and moistened with cobalt solution gives a deep blue color (alumina). Partially decomposed by sulphuric acid, and completely on fusion with alkaline carbonates.

Diff.—Resembles some talc, but distinguished by the reaction for alumina with cobalt solution.

Obs.—Compact pyrophyllite is the material or base of some schistose rocks. The foliated variety is often the gangue of cyanite. Occurs in the Ural; at Westanå, Sweden; near Ottrez, Luxembourg; Ouro Preto, Brazil.

Also in white stellate aggregations in Cottonstone Mtn., Mecklenburg Co., N. C ; in Chesterfield Dist., S. C., with lazulite and cyanite; in Lincoln Co., Ga., on Graves Mtn. The compact kind, at Deep River, N. C., is extensively used for making slate-pencils and resembles the so-called agalmatolite or pagodite of China, often used for ornamental carvings.

ALLOPHANE.

Amorphous. In incrustations, usually thin, with a mammillary surface, and hyalite-like; sometimes stalactitic. Occasionally almost pulverulent.

Fracture imperfectly conchoidal and shining, to earthy. Very brittle. H. = 3. G. = 1·85–1·89. Luster vitreous to subresinous; bright and waxy internally. Color pale sky-blue, sometimes greenish to deep green, brown, yellow or colorless. Streak uncolored. Translucent.

Comp.—Hydrous aluminium silicate, $Al_2SiO_5 + 5H_2O$ = Silica 23·8, alumina 40·5, water 35·7 = 100. Some analyses give 6 equivalents of water = Silica 22·2, alumina 37·8, water 40·0 = 100.

Impurities are often present. The coloring matter of the blue variety is due to traces of chrysocolla, and substances intermediate between allophane and chrysocolla (mixtures) are not uncommon. The green variety is colored by malachite, and the yellowish and brown by iron.

Pyr., etc.—Yields much water in the closed tube. B.B. crumbles. but is infusible. Gives a blue color with cobalt solution. Gelatinizes with hydrochloric acid.

Obs.—Allophane is regarded as a result of the decomposition of some aluminous silicate (feldspar, etc.); and it often occurs incrusting fissures or cavities in mines, especially those of copper and limonite, and even in beds of coal.

Named from *αλλος*. *other*, and *φαίνεσθαι*, *to appear*, in allusion to its change of appearance under the blowpipe.

Collyrite. $2Al_2O_3.SiO_2.9H_2O$. A clay-like mineral, white. with a glimmering luster, greasy feel. and adhering to the tongue G. = 2–2·15. From Ezquerra in the Pyrenees.

Schrötterite. $8Al_2O_3.3SiO_2.30H_2O$. Resembles allophane; sometimes like gum in appearance. H. = 3–3·5. G. = 1·95–2·05. Color pale green or yellowish. From Dollinger mountain, near Freienstein, in Styria; at the Falls of Little River, on the Sand Mtn., Cherokee Co., Alabama.

The following are clay-like minerals or mineral substances: Sinopite, smectite, catlinite.

Cenosite. $H_4Ca_2(Y,Er)_2CSi_4O_{17}$. Color yellowish brown. From Hitterö, Norway.

Thaumasite. $CaSiO_3.CaCO_3.CaSO_4.15H_2O$. Massive, compact, crystalline. Cleavage in traces. H. = 3·5. G. = 1·877. Color white. Occurs filling cavities and crevices at the Bjelke mine, near Åreskuta, Jemtland, Sweden; at first soft, but hardens on exposure to the air. Also in fibrous crystalline masses at Paterson, N. J.

Uranophane Uranotil. $CaO.2UO_3.2SiO_2 + 6H_2O$. In radiated aggregations; massive, fibrous. G. = 3·81–3·90. Color yellow. From the granite of Kupferberg, Silesia. *Uranotil* occurs at Wölsendorf, Bavaria; Mitchell Co., N. C.

CHRYSOCOLLA.

Cryptocrystalline; often opal-like or enamel-like in texture; earthy. Incrusting or filling seams. Sometimes botryoidal.

Fracture conchoidal. Rather sectile; translucent varieties brittle. H. = 2–4. G. = 2–2·238. Luster vitreous, shining, earthy. Color mountain-green, bluish green, passing into sky-blue and turquois-blue; brown to black when impure. Streak, when pure, white. Translucent to opaque.

Comp.—True chrysocolla appears to correspond to $CuSiO_3 + 2H_2O$ = Silica

34·3, copper oxide 45·2, water 20·5 = 100, the water being double that of dioptase.

Composition varies much through impuities; free silica, also alumina, black oxide of copper, oxide of iron (or limonite) and oxide of manganese may be present; the color consequently varies from bluish green to brown and black.

Pyr., etc.—In the closed tube blackens and yields water. B.B. decrepitates, colors the flame emerald-green, but is infusible. With the fluxes gives the reactions for copper. With soda and charcoal a globule of metallic copper. Decomposed by acids without gelatinization.

Obs—Accompanies other copper ores, occurring especially in the upper part of veins. Found in copper mines in Cornwall; Hungary; Siberia; Saxony; South Australia; Chili, etc.

In the U. S., similarly at the Schuyler's mines, New Jersey; at Morgantown, Pa.; at the Clifton mines, Graham Co., Arizona; Emma mine, Utah.

Chrysocolla is from χρυσος, *gold*, and κόλλα, *glue*, and was the name of a material used in soldering gold. The name is often applied now to borax, which is so employed.

CHLOROPAL.

Compact massive, with an opal-like appearance; earthy.

H. = 2·5–4·5. G. = 1·727–1·870, earthy varieties, the second a conchoidal specimen; 2·105, Ceylon, Thomson. Color greenish yellow and pistachio-green. Opaque to subtranslucent. Fragile. Fracture conchoidal and splintery to earthy. Feebly adhering to the tongue, and meager to the touch.

Var.—*Chloropal* has the above-mentioned characters, and was named from the Hungarian mineral occurring at Unghwar.

Nontronite is pale straw-yellow or canary-yellow, and greenish, with an unctuous feel; flattens and grows lumpy under the pestle, and is polished by friction; from Nontron, Dept. of Dordogne, France. *Pinguite* is siskin- and oil-green, extremely soft, like new-made soap, with a slightly resinous luster, not adhering to the tongue; from Wolkenstein in Saxony. *Graminite* has a grass-green color (whence the name), and occurs at Menzenberg, in the Siebengebirge, in thin fibrous seams, or as delicate lamellæ.

Comp.—A hydrated silicate of ferric iron, perhaps with the general formula $H_6Fe_2(SiO_4)_3 + 2H_2O$ or $Fe_2O_3.3SiO_2.5H_2O$ = Silica 41·9, iron sesquioxide 37·2, water 20·9 = 100. Alumina is present in some varieties.

The water and silica both vary much. The Hungarian chloropal occurs mixed with opal, and graduates into it, and this accounts for the high silica of some of its analyses.

Obs.—Localities mentioned above. *Chloropal* occurs also at Meenser Steinberg near Göttingen; *pinguite* at Sternberg, Moravia. On Lehigh Mt., Pa., south of Allentown, occurs in connection with iron deposits.

HŒFERITE. An iron silicate near chloropal. Color green. From Křitz, Bohemia.

Hisingerite. A hydrated ferric silicate, of uncertain composition. Amorphous, compact. Fracture conchoidal. H. = 3. G. = 2·5–3·0. Luster greasy. Color black to brownish black. Streak yellowish brown. From Riddarhyttan, Tunaberg, Sweden; Långban, etc., Norway.

The following are hydrous manganese silicates.

Bementite. Approximately $2MnSiO_3.H_2O$. In soft radiated masses resembling pyrophyllite. G. = 2·981. Color pale grayish yellow. From the zinc mines of Franklin Furnace, N. J.

Caryopilite. Approximately $4MnO.3SiO_2.3H_2O$. In stalactitic and reniform shapes. G. = 2·83–2·91. Color brown. From the Harstig mine near Pajsberg, Sweden.

Neotocite. A hydrated silicate of manganese and iron, of doubtful composition, usually derived from the alteration of rhodonite. Amorphous Color black to dark brown and liver-brown.

TITANO-SILICATES, TITANATES.

This section includes the common calcium titano-silicate, Titanite; also a number of silicates which contain titanium, but whose relations are not altogether clear; further the titanate, Perovskite, and niobo-titanate, Dysanalyte, which is intermediate between Perovskite and the species Pyrochlore, Microlite, Koppite of the following chapter.

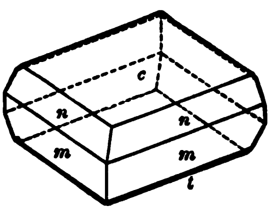
In general the part played by titanium in the many silicates in which it enters is more or less uncertain. It is probably in most cases, as shown in the preceding pages, to be taken as replacing the silicon; in others, however, it seems to play the part of a basic element; in schorlomite (p. 419) it may enter in both relations.

TITANITE. Sphene.

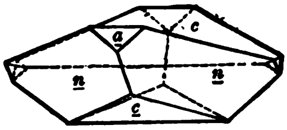
Monoclinic. Axes $\breve{a} : \breve{b} : \acute{c} = 0{\cdot}7547 : 1 : 0{\cdot}8543$; $\beta = 60°\ 17'$.

mm''', 110 ∧ $1\bar{1}0$ = 66° 29'.
cx, 001 ∧ 102 = 21° 0'.
ss', 021 ∧ $0\bar{2}1$ = 112° 8'.
nn', 111 ∧ $1\bar{1}1$ = 43° 49'.
ll', $\bar{1}12$ ∧ $\bar{1}\bar{1}2$ = 46° 7½'.
cn, 001 ∧ 111 = 38° 16'.
cm, 001 ∧ 110 = 65° 30'.
cl, 001 ∧ $\bar{1}12$ = 40° 34'.

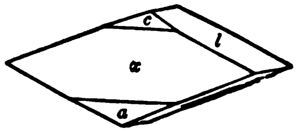
916.



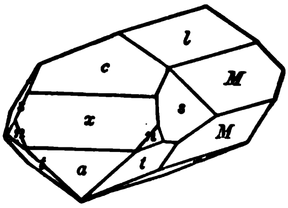
918.



917.



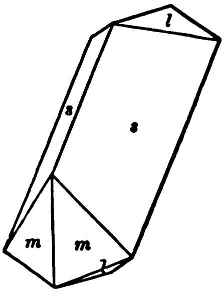
919.



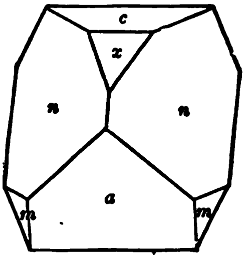
Twins: tw. pl. *a* rather common, both contact-twins and cruciform penetration-twins. Crystals very varied in habit; often wedge-shaped and flattened ∥ *c*; also prismatic. Sometimes massive, compact; rarely lamellar.

Cleavage: *m* rather distinct; *a*, *l* ($\bar{1}12$) imperfect; in greenovite, *n* (111) easy, *t* ($\bar{1}11$) less so (Dx.). Parting often easy ∥ η (221) due to twinning lamellæ. H. = 5–5·5. G. = 3·4–3·56; 3·541 Chester, Pirsson. Luster adamantine to resinous. Color brown, gray, yellow, green, rose-red and black. Streak white, slightly reddish in greenovite. Transparent to opaque.

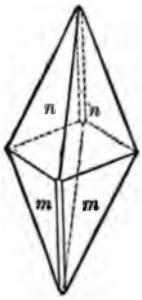
920.



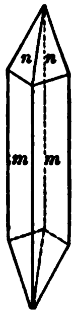
921.



922.



923.



Pleochroism in general rather feeble, but distinct in deep-colored kinds: c, red with tinge of yellow; b, yellow, often greenish; a, nearly colorless. Optically +. Ax. pl. $\parallel b$. Bx nearly $\perp x$ (102), i.e., $\mathrm{Bx} \wedge \dot{c} = +51°$. Dispersion $\rho > v$ very large, and hence the peculiarity of the axial interference-figure in white light. Axial angles variable. $2E_r = 50°$ to $90°$. $\beta_y = 1·894$. Birefringence high, $\gamma - \alpha = 0·121$.

Var.—*Ordinary.* (*a*) *Titanite;* brown to black, the original being thus colored, also opaque or subtranslucent. (*b*) *Sphene* (named from *σφήν, a wedge*); of light shades, as yellow, greenish, etc., and often translucent; the original was yellow. *Ligurite* is an apple-green sphene. *Spinthere* (or Semeline) a greenish kind. *Lederite* is brown, opaque, or subtranslucent, of the form in Fig. 916.

Titanomorphite is a white mostly granular alteration-product of rutile and ilmenite, not uncommon in certain crystalline rocks; here also belongs most leucoxene (see p. 887).

Manganesian; Greenovite. Red or rose-colored, owing to the presence of a little manganese; from St. Marcel.

Containing yttrium or cerium. Here belong grothite, alshedite, eucolite-titanite.

Comp.—$CaTiSiO_5$ or $CaO.TiO_2.SiO_2$ = Silica 30·6, titanium dioxide 40·8, lime 28·6 = 100. Iron is present in varying amounts, sometimes manganese and also yttrium in some kinds.

Pyr., etc.—B.B. some varieties change color, becoming yellow, and fuse at 3 with intumescence, to a yellow, brown or black glass. With borax they afford a clear yellowish-green glass. Imperfectly soluble in heated hydrochloric acid; and if the solution be concentrated along with tin, it becomes of a fine violet color. With salt of phosphorus in R.F. gives a violet bead; varieties containing much iron require to be treated with the flux on charcoal with metallic tin. Completely decomposed by sulphuric and hydrofluoric acids.

Diff.—Characterized by its oblique crystallization, a wedge-shaped form common; by resinous (or adamantine) luster; hardness less than that of staurolite and greater than that of sphalerite. The reaction for titanium is distinctive, but less so in varieties containing much iron.

Distinguished in thin sections by its acute-angled form, often lozenge-shaped; its generally pale brown tone; very high relief and remarkable birefringence, causing the section to show white of the higher order; by its biaxial character (showing many lemniscate curves); and by its great dispersion, which produces colored hyperbolas.

Obs.—Titanite, as an accessory component, is widespread as a rock-forming mineral, though confined mostly to the acidic feldspathic igneous rocks; it is much more common in the plutonic granular types than in the volcanic forms. Thus it is found in the more basic hornblende granites, syenites, and diorites, and is especially common and characteristic in the nephelite-syenites. It occurs also in the metamorphic rocks and especially in the schists, gneisses, etc., rich in magnesia and iron and in certain granular limestones. It is also found in beds of iron ore; commonly associated minerals are pyroxene, amphibole, chlorite, scapolite, zircon, apatite, etc. In cavities in gneiss and granite, it often accompanies adularia, smoky quartz, apatite, chlorite, etc.

Occurs at various points in the Grisons, Switzerland, associated with feldspar and chlorite; Tavetsch; in the St. Gothard region; Zermatt in the Valais; Maderanerthal in Uri; also elsewhere in the Alps; in Dauphiné (*spinthère*); at Ala, Piedmont (*ligurite*); at St. Marcel, in Piedmont; at Schwarzenstein and Rothenkopf in the Zillerthal, Pfitsch, Tyrol; Zöptau, Moravia; near Tavistock; near Tremadoc, in North Wales; in titanic iron at Arendal, in Norway; with magnetite at Nordmark, Sweden; Achmatovsk, Ural. Occasionally found among volcanic rocks, as at Lake Laach (*semeline*) and at Andernach on the Rhine.

In *Maine*, in fine crystals at Sandford. In *Mass.*, in gneiss, in the east part of Lee; at Bolton with pyroxene and scapolite in limestone. In *N. York*, at Roger's Rock on Lake George, abundant in small brown crystals; at Gouverneur, in black crystals in granular limestone; in Diana near Natural Bridge, Lewis Co., in large dark brown crystals, among which is the variety *lederite;* at Rossie, Fine, Pitcairn, St. Lawrence Co.; in Orange Co., in limestone; near Edenville, in light brown crystals in limestone; at Brewster, at the Tilly Foster iron mine. In *N. Jersey*, at Franklin Furnace, honey-yellow. In *Penn.*, Bucks Co., three miles west of Attleboro', associated with wollastonite and graphite. In *N. Carolina*, at Statesville, Iredell Co., yellowish white with sunstone; also Buncombe Co., Alexander Co., and other points.

Occurs in *Canada*, at Grenville, Argenteuil Co.; also Buckingham, Templeton, Wakefield, Hull, Ottawa Co.; at N. Burgess, honey-yellow; near Eganville, Renfrew Co., Ontario, in very large dark brown crystals with apatite, amphibole, zircon.

Keilhauite. A titano-silicate of calcium, aluminium, ferric iron, and the yttrium metals. Crystals near titanite in habit and angles. H. = 6·5. G. = 3·52–3·77. Color brownish black. From near Arendal, Norway.

Guarinite. $CaTiSiO_5$, as for titanite. In minute thin tables, flattened ∥ *b* (010), nearly tetragonal in form. H. = 6. G. = 3·487. Color sulphur-yellow, honey-yellow. Found in a grayish trachyte on Monte Somma.

Tscheffkinite. A titano-silicate of the cerium metals, iron, etc., but an alteration-product, more or less heterogeneous, and the composition of the original mineral is very uncertain. Massive, amorphous. H. = 5–5·5. G. = 4·508–4·549. Color velvet-black. From the Ilmen mountains in the Ural. Also from S. India, probably Kanjamalai Hill, Salem distr. An isolated mass weighing 20 lbs. has been found on Hat Creek, near Massie's Mills, Nelson Co, Virginia; also found, south of this point, in Bedford Co.

Astrophyllite. Probably $\overset{\text{I}}{R}_4\overset{\text{II}}{R}_4Ti(SiO_4)_4$ with $\overset{\text{I}}{R}$ = H, Na, K, and $\overset{\text{II}}{R}$ = Fe, Mn chiefly, including also Fe_2O_3. In elongated crystals; also in thin strips or blades; sometimes in stellate groups. Cleavage: *b* perfect like mica, but laminæ brittle. H. = 3. G. = 3·3–3·4. Luster submetallic, pearly. Color bronze-yellow to gold-yellow.

Occurs on the small islands in the Langesund fiord, near Brevik, Norway, in elæolite-syenite, embedded in feldspar, with catapleiite, ægirite, black mica, etc. Similarly at Kangerdluarsuk, Greenland. Also with arfvedsonite and zircon at St. Peter's Dome, Pike's Peak, El Paso Co., Colo.

Johnstrupite. A silicate of the cerium metals, calcium and sodium chiefly, with titanium and fluorine. In prismatic crystals. G. = 3·29. From near Barkevik, Norway.

Mosandrite. Near johnstrupite in form and composition and from the same region.

Rinkite, also near johnstrupite, is from Greenland.

Neptunite. A titano-silicate of iron (manganese) and the alkali metals. In prismatic monoclinic crystals. H. = 5–6. G. = 3·23. Color black. Southern Greenland.

PEROVSKITE. Perofskite.

Isometric or pseudo-isometric. Crystals in general (Ural, Zermatt) cubic in habit and often highly modified, but the faces often irregularly distributed. Cubic faces striated parallel to the edges and apparently penetration-twins, as if of pyritohedral individuals. Also in reniform masses showing small cubes.

Cleavage: cubic, rather perfect. Fracture uneven to subconchoidal. Brittle. H. = 5·5. G. = 4·017–4·039 Zermatt. Luster adamantine to metallic-adamantine. Color pale yellow, honey-yellow, orange-yellow, reddish brown, grayish black. Streak colorless, grayish. Transparent to opaque. Usually exhibits anomalous double refraction.

Geometrically considered, perovskite conforms to the isometric system; optically, however, it is uniformly biaxial and usually positive. The molecular structure (also as developed by etching, Baumhauer) seems to correspond to orthorhombic symmetry. Cf. Art. 411.

Comp.—Calcium titanate, $CaTiO_3$ = Titanium dioxide 58·9, lime 41·1 = 100. Iron is present in small amount replacing the calcium.

Pyr., etc.—In the forceps and on charcoal infusible. With salt of phosphorus in O.F. dissolves easily, giving a greenish bead while hot, which becomes colorless on cooling; in R.F. the bead changes to grayish green, and on cooling assumes a violet-blue color. Entirely decomposed by boiling sulphuric acid.

Obs.—Occurs in small crystals, associated with chlorite, and magnetic iron in chlorite slate, at Achmatovsk, near Zlatoust, in the Ural; at Schelingen in the Kaiserstuhl, in granular limestone; in the valley of Zermatt, near the Findelen glacier; at Wildkreuzjoch, between Pfitsch and Pfunders in Tyrol. Sometimes noted in microscopic octahedral crystals as a rock constituent; thus in nephelite- and melilite-basalts; also in serpentine (altered peridotite) at Syracuse, N. Y.

Knopite. Near perovskite but contains cerium. In black isometric crystals. From Alnö, Sweden.

Dysanalyte. A titano-niobate of calcium and iron. In cubic crystals. From the granular limestone of Vogtsburg, Kaiserstuhlgebirge, Baden. Has previously been called perovskite, but is in fact intermediate between the titanate, perovskite, and the niobates, pyrochlore and koppite.

A related mineral, which has also long passed as perovskite, occurs with magnetite, brookite, rutile, etc., at Magnet Cove, Arkansas. It is in octahedrons or cubo-octahedrons, black or brownish black in color and submetallic in luster.

See also the allied titanate, bixbyite, mentioned on p. 343.

Geikielite. Magnesium titanate, $MgTiO_3$. Massive, as rolled pebbles. H. = 6. G. = 4. Color bluish or brownish black. From Ceylon.

Oxygen Salts.

3. NIOBATES, TANTALATES.

The Niobates (Columbates) and Tantalates are chiefly salts of metaniobic and metatantalic acid, RNb_2O_6 and RTa_2O_6; also in part Pyroniobates, RNb_2O_7, etc. Titanium is prominent in a number of the species, which are hence intermediate between the niobates and titanates. Niobium and tantalum also enter into the composition of a few rare silicates, as wöhlerite, låvenite, etc.

The following groups may be mentioned:

The isometric PYROCHLORE GROUP, including pyrochlore, microlite, etc
The tetragonal FERGUSONITE GROUP, including fergusonite and sipylite
The orthorhombic COLUMBITE GROUP, including columbite and tantalite
Also the orthorhombic SAMARSKITE GROUP, including yttrotantalite, samarskite, and ånnerodite.

The species belonging in this class are for the most part rare, and are hence but briefly described.

PYROCHLORE.

Isometric. Commonly in octahedrons; also in grains.

Cleavage: octahedral, sometimes distinct. Fracture conchoidal. Brittle. H. = 5–5·5. G. = 4·2–4·36. Luster vitreous or resinous, the latter on fracture surfaces. Color brown, dark reddish or blackish brown. Streak light brown, yellowish brown. Subtranslucent to opaque.

Comp.—Chiefly a niobate of the cerium metals, calcium and other bases, with also titanium, thorium, fluorine. Probably essentially a metaniobate with a titanate, $RNb_2O_6.R(Ti,Th)O_3$; fluorine is also present.

The following are analyses by Rammelsberg:

	G.	Nb_2O_5	TiO_2	ThO_2	Ce_2O_3	CaO	FeO	MgO	NaO_2	F
Miask	4·359	‡ 53·19	10·47	7·56	7·00	14·21	1·84	0·22	5·01	—
Fredriksvärn	4·228	47·18	13·52	—	7·30	15·94	10·03	0·19	3·12	2·90

[ign. 1·39 = 101·52

Obs.—Occurs in elæolite-syenite at Fredriksvärn and Laurvik, Norway; on the island Lövö, opposite Brevik, and at several points in the Langesund fiord; near Miask in the Ural. Named from πῦρ, *fire*, and χλωρός, *green*, because B.B. it becomes yellowish green.

Koppite. Essentially a pyroniobate of cerium, calcium, etc., near pyrochlore. In minute brown dodecahedrons. G. = 4·45–4·56. From Schelingen, Kaiserstuhl, embedded in limestone.

Hatchettolite. A tantalo-niobate of uranium, near pyrochlore. In octahedrons with *a* (100) and *m* (311). G. = 4·77–4·90. Color yellowish brown. Occurs with samarskite, at the mica mines of Mitchell Co., North Carolina.

Microlite. Essentially a calcium pyrotantalate, $Ca_2Ta_2O_7$, but containing also tantalum, fluorine and a variety of bases in small amount. Isometric. Habit octahedral; crystals often very small and highly modified (Fig. 109, p. 40). H. = 5·5. G. = 5·485–5·562; 6·13 Virginia. Color pale yellow to brown, rarely hyacinth-red. From Chesterfield, Mass., in albite; Branchville, Conn.; Utö, Sweden. Also in fine crystals up to 1 in. in diameter at the mica mines at Amelia Court-House, Amelia Co., Va.

Pyrrhite. Probably a niobate related to pyrochlore, and perhaps identical with microlite. Occurs in minute orange-yellow octahedrons. From Alabashka, near Mursinka in the Ural.

FERGUSONITE. Tyrite. Bragite.

Tetragonal-pyramidal. Axis $\dot{c}$ = 1·4643. Crystals pyramidal or prismatic in habit.

Cleavage: *s* (111) in traces. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 5·8, diminishing to 4·3 when largely hydrated. Luster externally dull, on the fracture brilliantly vitreous and submetallic. Color brownish black; in thin scales pale liver-brown. Streak pale brown. Subtranslucent to opaque.

Comp.—Essentially a metaniobate (and tantalate) of yttrium with erbium, cerium, uranium, etc., in varying amounts; also iron, calcium, etc. General formula $\overset{\text{III}}{R}(Nb,Ta)O_4$ with $\overset{\text{III}}{R}$ = Y,Er,Ce.

Water is usually present and sometimes in considerable amount, but probably not an original constituent; the specific gravity falls as the amount increases. Analyses by Rammelsberg:

	G.	Nb_2O_5	Ta_2O_5	UO_2	WO_3	SnO_2	Y_2O_3	Er_2O_3	Ce_2O_3	FeO	CaO	H_2O
Greenland, *Ferg.*	5·577	44·45	6·30	2·58	0·15	0·47	24·87	9·81	7·63[a]	0·74	0·61	1·49
												[= 99·10
Ytterby, *yw.*	4·774	28·14	27·04	2·13	—	—	24·45	8·26	—	0·72	4·17	5·12
												[= 100·03

[a] Incl. 5·63 Di_2O_3,La_2O_3.

Obs.—From Cape Farewell in Greenland, in quartz; also at Ytterby, Sweden, and Kårarfvet. *Tyrite* is associated with euxenite at Hampemyr on the island of Tromö, and Helle on the mainland; *bragite* is from Hellè, Narestö, etc., Norway.

Found in the U. S., at Rockport, Mass., in granite; in the Brindletown gold district, Burke Co., N. C., in gold washings; with zircon in Anderson Co., S. Carolina; at the gadolinite locality in Llano Co., Texas, in considerable quantity.

Sipylite. A niobate of erbium chiefly, also the cerium metals, etc., near fergusonite in form. Rarely in octahedral crystals. Usually in irregular masses. G. = 4·89. Color brownish black to brownish orange. Occurs sparingly with allanite in Amherst Co., Virginia.

COLUMBITE-TANTALITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·8285 : 1 : 0·8898.

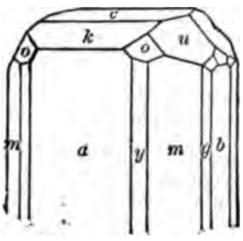
yy', 210 ∧ 2$\bar{1}$0 = 45° 0'.
mm''', 110 ∧ 1$\bar{1}$0 = 79° 17'.
gg', 130 ∧ $\bar{1}$30 = 43° 50'.
ck, 001 ∧ 103 = 19° 42'.
cq, 001 ∧ 023 = 30° 41'.

ce, 001 ∧ 021 = 60° 40'.
ao, 100 ∧ 111 = 51° 16'.
cu, 001 ∧ 133 = 43° 48'.
uu', 133 ∧ $\bar{1}$33 = 29° 57'.
uu''', 133 ∧ 1$\bar{3}$3 = 79° 54'.

Twins: tw. pl. *e* (021) common, usually contact-twins, heart-shaped (Figs. 347, p. 118), also penetration-twins; further tw. pl. *q* (0$\bar{2}$3) rare (Fig. 404, p. 281). Crystals short prismatic, often rectangular prisms with the pinacoids, *a b c*, prominent; also thin tabular ∥ *a*; the pyramids often but slightly developed, sometimes, however, acutely terminated by *u* (133) alone. Also in large groups of parallel crystals, and massive.

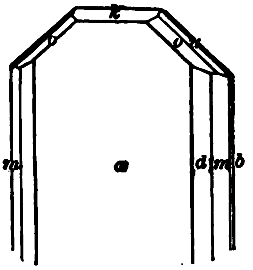
Cleavage: *a* rather distinct; *b* less so. Fracture subconchoidal to uneven. Brittle. H. = 6. G. = 5·3–7·3, varying with the composition (see below). Luster submetallic, often very brilliant, sub-resinous. Color iron-black, grayish and brownish black, opaque; rarely reddish brown and translucent; frequently iridescent. Streak dark red to black.

924.



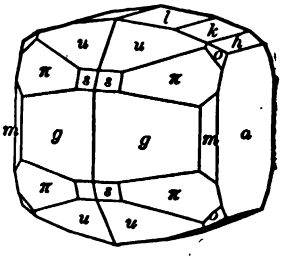
Middletown.

925.



Black Hills.

926.



Greenland.

Comp., Var.—Niobate and tantalate of iron and manganese, (Fe,Mn)(Nb,Ta)$_2$O$_6$, passing by insensible gradations from normal COLUMBITE, the nearly pure niobate, to normal TANTALITE, the nearly pure tantalate. The iron and manganese also vary widely. Tin and wolfram are present in small amount. The percentage composition for $FeNb_2O_6$ = Niobium pentoxide 82·7, iron protoxide 17·3 = 100; for $FeTa_2O_6$ = Tantalum pentoxide 86·1, iron protoxide 13·9 = 100

In some varieties, *manganocolumbite* or *manganotantalite*, the iron is largely replaced by manganese.

The connection between the specific gravity and the percentage of metallic acids is shown in the following table:

	G.	Ta_2O_5		G.	Ta_2O_5
Greenland	5·36	3·3	Bodenmais	5·92	27·1
Acworth, N. H.	5·65	15·8	Haddam	6·05	30·4
Limoges	5·70	13·8	Bodenmais	6·06	35·4
Bodenmais (*Dianite*)	5·74	13·4	Haddam	6·13	31·5
Haddam	5·85	10·0			
			Tantalite	7·03	65·6

Diff.—Distinguished (from black tourmaline, etc.) by orthorhombic crystallization, rectangular forms common; high specific gravity; submetallic luster, often with iridescent surface; cleavage much less distinct than for wolframite.

Pyr., etc.—For *tantalite*, B.B. alone unaltered. With salt of phosphorus dissolves slowly, giving an iron glass, which in R.F. is pale yellow on cooling; treated with tin on charcoal it becomes green. Decomposed on fusion with potassium bisulphate in the platinum spoon, and gives on treatment with dilute hydrochloric acid a yellow solution and a heavy white powder, which, on addition of metallic zinc, assumes a smalt-blue color; on dilution with water the blue color soon disappears. *Columbite*, when decomposed by fusion with caustic potash, and treated with hydrochloric and sulphuric acids, gives, on the addition of zinc, a blue color more lasting than with tantalite. Partially decomposed when the powdered mineral is evaporated to dryness with concentrated sulphuric acid, its color is changed to white, light gray, or yellow, and when boiled with hydrochloric acid and metallic zinc it gives a beautiful blue.

Obs.—Columbite occurs at Rabenstein and Bodenmais, Bavaria, in granite; Tammela, in Finland; Chanteloube, near Limoges, in pegmatite with tantalite; near Miask, in the Ilmen Mts., with samarskite; in the gold-washings of the Sanarka region in the Ural; in Greenland, in cryolite, at Ivigtut (or Evigtok), in brilliant crystals.

In the United States, in *Maine*, at Standish, in splendent crystals in granite; also at Stoneham with cassiterite, etc. In *N. Hampshire*, at Acworth, at the mica mine. In *Mass.*, at Chesterfield; Northfield, Mass. In *Connecticut*, at Haddam, in a granite vein; near Middletown; at Branchville, Fairfield Co., in a vein of albitic granite, in large crystals and aggregates of crystals, also in minute translucent crystals (*manganocolumbite*), upon spodumene. In *N. York*, at Greenfield, with chrysoberyl. In *Penn.*, Mineral Hill, Delaware Co. In *Virginia*, Amelia Co., in fine splendent crystals with microlite, monazite, etc. In *N. Carolina*, with samarskite at the mica mines of Mitchell Co. In *Colorado*, on microcline at the Pike's Peak region; Turkey Creek, Jefferson Co. In *S. Dakota*, in the Black Hills region, common in the granite veins. In *California*, King's Creek distr., Fresno Co.

Mangantantalite (Nordenskiöld) from Utö, Sweden, occurs with petalite, lepidolite, microlite, etc. *Manganotantalite* (Arzruni) is from gold-washings in the Sanarka region in the Ural.

Massive tantalite occurs in Finland, in Tammela, at Härkäsaari near Torro; in Kimito, at Skogböle; in Somero at Kaidasuo, and in Kuortane at Katiala, with lepidolite, tourmaline, and beryl; in Sweden, near Falun, at Broddbo and Finbo; in France, at Chanteloube near Limoges, in pegmatite. In the U. S., in Yancey Co., N. C.; Coosa Co., Ala.; also in the Black Hills, S. Dakota.

SKOGBÖLITE is essentially $FeTa_2O_6$, like normal tantalite, but occurs in prismatic crystals of different angles; the prism is near that of samarskite. From Härkäsaari in Tammela, Finland; also from Skogböle in Kimito. IXIOLITE, from Skogböle, is a niobo-tantalate of iron and manganese; also containing tin; relations doubtful.

Tapiolite. $Fe(Ta,Nb)_2O_6$. Like tantalite, but occurring in square octahedrons. G. = 7·496. Color pure black. From the Kulmala farm, Tammela, Finland.

YTTROTANTALITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}5412 : 1 : 1{\cdot}1330$. Crystals prismatic, $mm''' = 56° 50'$.

Cleavage: *b* very indistinct. Fracture small conchoidal. H. = 5–5·5. G. = 5·5–5·9. Luster submetallic to vitreous and greasy. Color black, brown, brownish yellow, straw-yellow. Streak gray to colorless. Opaque to subtranslucent.

Comp.—Essentially $\overset{ii}{R}\overset{iii}{R}_2(Ta,Nb)_4O_{15} + 4H_2O$, with $\overset{ii}{R} = Fe, Ca, \overset{iii}{R} = Y, Er,$ Ce, etc. The water may be secondary. Analysis by Rammelsberg:

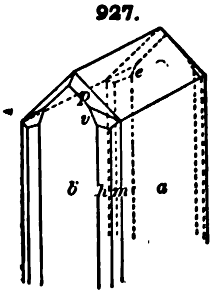
	Ta_2O_5	Nb_2O_5	WO_3	SnO_2	Y_2O_3	Er_2O_3	Ce_2O_3	UO_3	FeO	CaO	H_2O
G. = 5·425	46·25	12·32	2·36	1·12	10·52	6·71	2·22	1·61	3·80	5·73	6·31 [= 98·95

The so-called yellow yttrotantalite of Ytterby and Kårarfvet belongs to fergusonite.

Obs.—Occurs in Sweden at Ytterby, near Vaxholm, in red feldspar; at Finbo and Broddbo, near Falun.

SAMARSKITE.

927.



Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}5456 : 1 : 0{\cdot}5178$. Crystals rectangular prisms (*a*, *b*), with *e* (101) prominent. Angles, $mm''' = 57° 14'$; $ee' = 87°$. Faces rough. Commonly massive, and in flattened embedded grains.

Cleavage: *b* imperfect. Fracture conchoidal. Brittle. H. = 5–6. G. = 5·6–5·8. Luster vitreous to resinous, splendent. Color velvet-black. Streak dark reddish brown. Nearly opaque.

Comp.—$\overset{ii}{R}_3\overset{iii}{R}_2(Nb,Ta)_6O_{21}$ according to Rg., with $\overset{ii}{R} = Fe$, Ca, UO_2, etc.; $\overset{iii}{R}$ = cerium and yttrium metals chiefly. Analyses by Rammelsberg:

	G.	Ta_2O_5	Nb_2O_5	SnO_2,WO_3	UO_3	Ce_2O_3[a]	Y_2O_3	Er_2O_3	FeO	TiO_2	
N. Carolina	5·839	14·36	41·07	0·16	10·90	2·37	6·10	10·80	14·61	0·56[b]	= 100·93
Miask	5·672	—	55·34	0·22	11·94	4·33	8·80	3·82	14·30	1·08	= 99·83

[a] Incl. Di_2O_3,La_2O_3. [b] Incl. SiO_2.

Pyr., **etc.**—In the closed tube decrepitates, glows, cracks open, and turns black. B.B. fuses on the edges to a black glass. With salt of phosphorus in both flames an emerald-green bead. With soda yields a manganese reaction. Decomposed on fusion with potassium bisulphate, yielding a yellow mass which on treatment with dilute hydrochloric acid separates white tantalic acid, and on boiling with metallic zinc gives a fine blue color. In powder sufficiently decomposed on boiling with concentrated sulphuric acid to give the blue reduction test when the acid fluid is treated with metallic zinc or tin.

Obs.—Occurs in reddish brown feldspar, with æschynite and columbite in the Ilmen mountains, near Miask. In the United States, rather abundant and sometimes in large masses, up to 20 lbs., at the mica mines in Mitchell Co., N. Carolina, intimately associated with columbite; sparingly elsewhere.

Ånnerödite. Essentially a pyro-niobate of uranium and yttrium. In prismatic crystals, often resembling columbite. H. = 6. G. = 5·7. Color black. From the pegmatite vein at Ånneröd, near Moss, Norway.

Hielmite. A stanno-tantalate (and niobate) of yttrium, iron, manganese, calcium. Crystals (orthorhombic) usually rough; massive. G. = 5·82. Color pure black. From the Kårarfvet mine, Falun, Sweden.

Æschynite. A niobate and titanate (thorate) of the cerium metals chiefly, also in small amount iron, calcium, etc. Crystals prismatic, orthorhombic. Fracture small conchoidal. Brittle. H. = 5–6. G. = 4 93 Hitterö; 5·168 Miask. Luster submetallic to resinous, nearly dull. Color nearly black, inclining to brownish yellow when translucent. Analysis by Rammelsberg

	Nb_2O_5	TiO_2	ThO_2	Ce_2O_3, $La_2(Di_2)O_3$	Y_2O_3, (Er_2O_3)	FeO	CaO
G. = 5·168	32·51	21·20	17·55	19·41	8·10	3·34	2·50 = 99·61

From Miask in the Ilmen Mts., in feldspar with mica and zircon; also with euclase in the gold sands of the Orenburg District, Southern Ural. From Hitterö, Norway. Named from αἰσχυνή, *shame*, by Berzelius, in allusion to the inability of chemical science, at the time of its discovery, to separate some of its constituents.

Polymignite. A niobate and titanate (zirconate) of the cerium metals, iron, calcium. Crystals slender prisms, vertically striated. G. = 4·77–4·85. Color black. Occurs at Fredriksvårn, Norway.

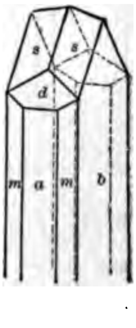
Euxenite. A niobate and titanate of yttrium, erbium, cerium and uranium. Crystals rare; commonly massive. H. = 6·5. G. = 4 7–5·0. Color brownish black. Analysis by Rammelsberg.

	G.	Nb_2O_5	TiO_2	Y_2O_3	Er_2O_3	Ce_2O_3	UO_2	FeO	H_2O
Alve	5·00	35·09	21·16	27·48	8·40	8·17	4·78	1·38	2·63 = 99·09

Occurs at Jölster in Norway; near Tvedestrand; at Alve, etc., near Arendal.

Polycrase. A niobate and titanate of yttrium, erbium, cerium, uranium, like euxenite. Crystals thin prismatic, orthorhombic. Fracture conchoidal. H. = 5–6. G. = 4·97–5·04. Luster vitreous to resinous. Color black, brownish in splinters. Analyses: 1, Mackintosh; 2, Hidden and Rammelsberg.

928.



	Nb_2O_5	Ta_2O_5	TiO_2	Y_2O_3	Er_2O_3	Ce_2O_3	UO_2	FeO	H_2O
Hitterö	20·35	4·00	26·59	23·32	7·53	2·61	7·70	2·72	4 02 [= 98 84
Henderson Co.,	19 48	—	29·31	27·55[a]	—	—	13·77	2·87	5·18[b] [= 98·16

[a] At. wght. 112. [b] UO_3.

From Hitterö, Norway, in granite with gadolinite: at Slättåkra, Småland, Sweden. In the U. States, in N. Carolina, in the gold-washings on Davis land, Henderson Co. with zircon, monazite, xenotime, magnetite; also in S. Carolina, four miles from Marietta in Greenville Co. Named from πολυς, *many*, and κράσις, *mixture*.

Oxygen Salts.

4. PHOSPHATES, ARSENATES, VANADATES, ANTIMONATES.

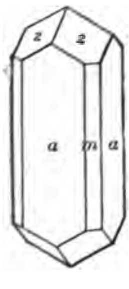
A. Anhydrous Phosphates, Arsenates, Vanadates, Anitmonates.

Normal phosphoric acid is H_3PO_4, and consequently normal phosphates have the formulas $\overset{I}{R}_3PO_4$, $\overset{II}{R}_3(PO_4)_2$ and $\overset{III}{R}PO_4$, and similarly for the arsenates, etc. Only a comparatively small number of species conform to this simple formula. Most species contain more than one metallic element, and in the prominent Apatite Group the radical (CaF), (CaCl) or (PbCl) enters; in the Wagnerite Group we have similarly $(\overset{II}{R}F)$ or (ROH).

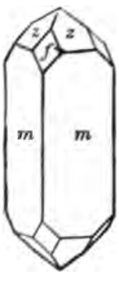
XENOTIME.

Tetragonal. Axis $\dot{c} = 0{\cdot}6187$, zz' $(111 \wedge \bar{1}11) = 55° 30'$, zz'' $(111 \wedge \bar{1}\bar{1}1) = 82° 22'$. In crystals resembling zircon in habit; sometimes compounded with zircon in parallel position (Fig. 314. p. 131). In rolled grains.

929.



930.



Cleavage: *m* perfect. Fracture uneven and splintery. Brittle. H. = 4–5. G. = 4·45–4·56. Luster resinous to vitreous. Color yellowish brown, reddish brown, hair-brown, flesh-red, grayish white, wine-yellow, pale yellow; streak pale brown, yellowish or reddish. Opaque. Optically +.

Comp.—Essentially yttrium phosphate, YPO_4 or $Y_2O_3.P_2O_5$ = Phosphorus pentoxide 38·6, yttria 61·4 = 100. The yttrium metals may include erbium in large amount; cerium is sometimes present; also silicon and thorium as in monazite.

Pyr., etc.—B.B. infusible. When moistened with sulphuric acid colors the flame bluish green. Difficultly soluble in salt of phosphorus. Insoluble in acids.

Diff.—Resembles zircon in its tetragonal form, but distinguished by inferior hardness and perfect prismatic cleavage.

Obs.—Occurs as an accessory mineral in granite veins; sometimes in minute embedded crystals generally distributed in granitic and gneissoid rocks. Found at Hitterö; at Moss, Kragerö, and from pegmatite veins at other points in Norway; at Ytterby, Sweden; the Fibia Berg, S.W. from St. Gothard and the Binnenthal, Switzerland. An accessory constituent in the muscovite-granites of Brazil.

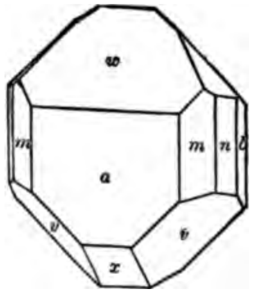
In the United States, in the gold washings of Clarksville, Georgia; in N. Carolina, Burke Co., Henderson Co., Mitchell Co.; in brilliant crystals in Alexander Co. with rutile, etc.; with tysonite near Pike's Peak, Colorado; rare on New York Island.

MONAZITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0·9693 : 1 : 0·9256$; $\beta = 76° 20'$.

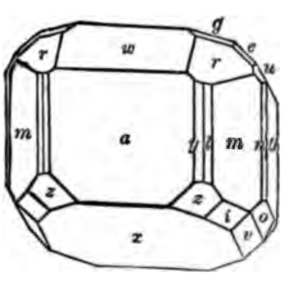
mm''', $110 \wedge 1\bar{1}0 = 86° 34'$.
aw, $100 \wedge 101 = 39° 12\frac{1}{2}'$.
a'x, $\bar{1}00 \wedge \bar{1}01 = 53° 31'$.
ee', $011 \wedge 0\bar{1}1 = 83° 56'$.
rr', $111 \wedge 1\bar{1}1 = 60° 40'$.
vv', $\bar{1}11 \wedge \bar{1}\bar{1}1 = 73° 19'$.

931.



Norwich, Ct.

932.



Switzerland.

Crystals commonly small, often flattened ‖ *a* or elongated ‖ axis *b*; sometimes prismatic by extension of *v* (111) (Fig. 324, p. 102); also large and coarse. In masses yielding angular fragments; in rolled grains.

Cleavage: *c* sometimes perfect (parting?); also, *a* distinct; *b* difficult; sometimes showing parting ‖ *c*, *m*. Fracture conchoidal to uneven. Brittle. H. = 5–5·5. G. = 4·9–5·3; mostly 5·0 to 5·2. Luster inclining to resinous. Color hyacinth-red, clove-brown, reddish or yellowish brown. Subtransparent to subtranslucent. Optically +. Ax. pl ⊥ *b* and nearly ‖ *a*. $Bx_a \wedge \grave{c} = +1°$ to 4°. Dispersion $\rho < v$ weak; horizontal weak. $2E_r = 29°$ to 31°.

Comp.—Phosphate of the cerium metals, essentially $(Ce,La,Di)PO_4$.

Most analyses show the presence of ThO_2 and SiO_2, usually, but not always, in the proper amount to form thorium silicate; that this is mechanically present is not certain but possible. Typical analyses: 1, Blomstrand; 2, Penfield.

	G	P_2O_5	Ce_2O_3	La_2O_3	$Y_2(Er)_2O_3$	SiO_2	ThO_2	
1. Arendal	5·15	27·55	29·20	26·26	3·82	1·86	9·57	X 2·34 = 100 60
2. Burke Co., N. C.	5·10	29·28	31·38	30·88	—	1·40	6·49	ign 0·20 = 99·63

X = Fe_2O_3 1·13, CaO 0 69, H_2O 0·52.

Pyr., etc.—B.B. infusible, turns gray, and when moistened with sulphuric acid colors the flame bluish green. With borax gives a bead yellow while hot and colorless on cooling; a saturated bead becomes enamel-white on flaming. Difficultly soluble in hydrochloric acid.

Obs.—Rather abundantly distributed as an accessory constituent of gneissoid rocks in certain regions, thus in North Carolina and Brazil. Occurs near Zlatoust in the Ilmen Mts., in granite. In Norway, near Arendal, and at Ånneröd. In small yellow or brown crystals (*turnerite*) in Dauphiné and Switzerland. Found also in the gold washings of Antioquia; in the diamond gravels of Brazil.

In the United States, formerly found with the sillimanite of Norwich, Conn.; also at Yorktown, N. Y. In large coarse crystals and masses in albitic granite with microlite, etc., at Amelia Court-House, Virginia. In Alexander Co., N. Carolina, in splendent crystals; in Mitchell, Madison, Burke, and McDowell counties, obtained in large quantities in rolled grains by washing the gravels.

Monazite is named from μονάζειν, *to be solitary*, in allusion to its rare occurrence.

Cryptolite occurs in wine-yellow prisms and grains in the green and red apatite of Arendal, Norway, and is discovered on putting the apatite in dilute nitric acid. It is probably monazite.

Berzeliite. $R_3As_2O_8$ (R = Ca,Mg,Mn). Isometric, usually massive. G = 4·03. Color bright yellow. From Långban, Sweden. *Pyrrharsenite* from the Sjö mines, Sweden, contains also antimony; color yellowish red. *Caryinite*, associated with berzeliite, is related, but contains lead; massive (monoclinic)·

Monimolite. An antimonate of lead, iron, and sometimes calcium; in part, $R_3Sb_2O_8$. [illegible] commonly massive, incrusting. G. = [illegible]. Color yellowish or brownish green. [illegible] the Harstig mine, Pajsberg.

Carminite. Perhaps $Pb_3As_2O_8.10FeAsO_4$. In clusters of fine needles; also in spheroidal [illegible] G. = 4·105. Color carmine to tile-red. From the Louise mine at Horhausen, Nassau.

Pucherite. Bismuth vanadate $BiVO_4$. In small orthorhombic crystals. H. = 4. [illegible] Color reddish brown. From the Pucher Mine, Schneeberg, Saxony.

Triphylite Group. Orthorhombic.

		$\breve{a} : \bar{b} : \dot{c}$
Triphylite	$Li(Fe,Mn)PO_4$	0·4348 : 1 : 0·5265
Lithiophilite	$Li(Mn,Fe)PO_4$	
Natrophilite	$NaMnPO_4$	

Orthophosphates of an alkali metal, lithium or sodium, with iron and manganese.

TRIPHYLITE-LITHIOPHILITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·4348 : 1 : 0·5265. Crystals rare, usually coarse and faces uneven. Commonly massive, cleavable to compact.

Cleavage: *c* perfect; *b* nearly perfect: *m* interrupted. Fracture uneven to subconchoidal. H. = 4·5–5. G. = 3·42–3·56. Luster vitreous to resinous. Color greenish gray to bluish in triphylite; also pale pink to yellow and clove-brown in lithiophilite. Streak uncolored to grayish white. Transparent to translucent.

Comp., Var.—A phosphate of iron, manganese and lithium, $Li(Fe,Mn)PO_4$, varying from the bluish-gray TRIPHYLITE with little manganese to the salmon-pink or clove-brown LITHIOPHILITE with but little iron.

Typical *Triphylite* is $LiFePO_4$ = Phosphorus pentoxide 45·0, iron protoxide 45·5, lithia 9·5 = 100. Typical *Lithiophilite* is $LiMnPO_4$ = Phosphorus pentoxide 45·3, manganese protoxide 45·1, lithia 9·6 = 100. Both Fe and Mn are always present.

Pyr., etc.—In the closed tube sometimes decrepitates, turns to a dark color, and gives off traces of water. B.B. fuses at 1·5, coloring the flame beautiful lithia-red in streaks, with a pale bluish green on the exterior of the cone of flame. With the fluxes reacts for iron and manganese; the iron reaction is feeble in pure lithiophilite. Soluble in hydrochloric acid.

Obs.—*Triphylite* is often associated with spodumene: occurs at Rabenstein, near Zwiesel, in Bavaria; Keityö, Finland; Norwich, Mass.; Peru, Me.; Grafton, N. H. Named from τρίς, *threefold*, and φυλή, *family*, in allusion to its containing three phosphates.

Lithiophilite occurs at Branchville, Fairfield Co., Conn., in a vein of albitic granite, with spodumene, manganese phosphates, etc.; also at Norway, Me. Named from *lithium* and φιλός, *friend*.

Natrophilite, $NaMnPO_4$. Near triphylite in form. Chiefly massive, cleavable. H. = 4·5–5. G. = 3·41. Color deep wine-yellow. Occurs sparingly at Branchville, Fairfield Co., Conn.

Beryllonite. A phosphate of sodium and beryllium, $NaBePO_4$. Crystals short prismatic to tabular, orthorhombic. H. = 5·5–6. G. = 2·845. Luster vitreous; on *c* pearly. Colorless to white or pale yellowish. From Stoneham, Maine.

Apatite Group.

General formula $R_5(F,Cl)[(P,As,V)O_4]_3 = (R(F,Cl))R_4[(P,As,V)O_4]_3$;

Apatite	$(CaF)Ca_4(PO_4)_3$	Fluor-apatite	$\dot{c} = 0{\cdot}7346$
	or $(CaCl)Ca_4(PO_4)_3$	Chlor-apatite	
Pyromorphite	$(PbCl)Pb_4(PO_4)_3$		0·7362
Mimetite	$(PbCl)Pb_4(AsO_4)_3$		0·7224
Vanadinite	$(PbCl)Pb_4(VO_4)_3$		0·7122

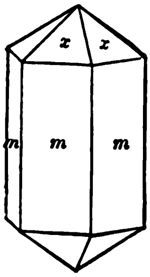
In addition to the above species, there are also certain intermediate compounds containing lead and calcium; others with phosphorus and arsenic, or arsenic and vanadium, as noted beyond. Further the rare calcium arsenate, Svabite, also seems to belong in this group.

The species of the APATITE GROUP crystallize in the hexagonal system, but all show, either by the subordinate faces, or in etching-figures, that they belong to the pyramidal group (p. 71). They are chemically phosphates, arsenates, vanadates of calcium or lead (also manganese), with chlorine or fluorine. The latter element is probably present as a univalent radical CaF (or CaCl), etc., in general RF (or RCl), replacing one hydrogen atom in the acid $\overset{\text{I}}{R}_9(PO_4)_3$, so that the general formula is $(\overset{\text{II}}{R}F)\overset{\text{II}}{R}_4(PO_4)_3$, and similarly for the arsenates. This is a more correct way of viewing the composition than the other method sometimes adopted, viz., $3R_3(PO_4)_2.RF_2$, etc.

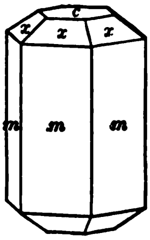
APATITE.

Hexagonal-pyramidal. Axis $\dot{c} = 0{\cdot}7346$.

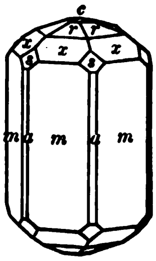
933.



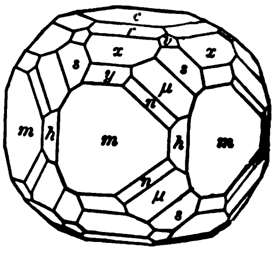
934.



935.

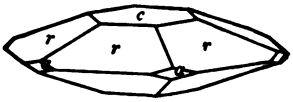


936.



cr, $0001 \wedge 10\bar{1}2 = 22° 59'$. *xx'*, $10\bar{1}1 \wedge 01\bar{1}1 = 37° 44\tfrac{1}{2}'$.
cx, $0001 \wedge 10\bar{1}1 = 40° 18'$. *ss'*, $11\bar{2}1 \wedge \bar{1}2\bar{1}1 = 48° 50'$.
cy, $0001 \wedge 20\bar{2}1 = 59° 29'$. *mμ*, $10\bar{1}0 \wedge 21\bar{3}1 = 30° 20'$.
rr', $10\bar{1}2 \wedge 01\bar{1}2 = 22° 31'$. *ms*, $10\bar{1}0 \wedge 11\bar{2}1 = 44° 17'$.

937.



Crystals varying from long prismatic to short prismatic and tabular. Also globular and reniform, with a fibrous or imperfectly columnar structure; massive, structure granular to compact.

Cleavage: *c* imperfect; *m* more so. Fracture conchoidal and uneven. Brittle. H. = 5, sometimes 4·5 when massive. G. = 3·17–3·23 cryst. Luster vitreous, inclining to subresinous. Streak white. Color usually sea-green, bluish green; often violet-blue; sometimes white; occasionally yellow, gray, red, flesh-red and brown. Transparent to opaque. Optically −. Birefringence low. $\omega_y = 1{\cdot}6461$, $\epsilon_y = 1{\cdot}6417$.

Var.—1. *Ordinary*. Crystallized, or cleavable and granular massive. Colorless to green, blue, yellow, flesh-red. (*a*) The ***asparagus-stone***, originally from Murcia, Spain, is yellowish green. ***Moroxite***, from Arendal, is in greenish blue and bluish crystals. (*b*) ***Lasurapatite*** is a sky-blue variety with lapis-lazuli in Siberia. (*c*) ***Francolite***, from Wheal Franco, near Tavistock, Devonshire, occurs in small crystalline stalactitic masses and in minute curving crystals.

Ordinary apatite is ***fluor-apatite***, containing fluorine often with only a trace of chlorine, up to 0·5 p. c.; rarely chlorine preponderates, and sometimes fluorine is entirely absent.

2. *Manganapatite* contains manganese replacing calcium to 10·5 p. c. MnO; color dark bluish green.

3. *Fibrous, concretionary, stalactitic. Phosphorite* includes the fibrous concretionary and partly scaly mineral from Estremadura, Spain, and elsewhere. *Eupyrchroite*, from Crown Point, N. Y., belongs here; it is concentric in structure. *Staffelite* occurs incrusting the phosphorite of Staffel in botryoidal, reniform, or stalactitic masses, fibrous and radiating. See p. 499.

4. *Earthy apatite; Osteolite.* Mostly altered apatite; coprolites are impure calcium phosphate.

Comp.—For *Fluor-apatite* $(CaF)Ca_4(PO_4)_3$; and for *Chlor-apatite* $(CaCl)\ Ca_4(PO_4)_3$; also written $3Ca_3P_2O_8 + CaF_2$ and $3Ca_3P_2O_8 + CaCl_2$. There are also intermediate compounds containing both fluorine and chlorine. The percentage composition for these normal varieties is as follows:

Fluor-apatite	P_2O_5 42·3	CaO 55·5	F 3·8 = 101·6	or $Ca_3P_2O_8$ 92·25	CaF_2 7·75 = 100
Chlor-apatite	P_2O_5 41·0	CaO 53·8	Cl 6·8 = 101·6	or $Ca_3P_2O_8$ 89·4	$CaCl_2$ 10·6 = 100

Fluor-apatite is much more common than the other variety; here belongs the apatite of the Alps, Spain, St. Lawrence Co., N. Y., Canada. Apatites in which chlorine is prominent are rare; this is true of some Norwegian kinds.

Pyr., etc.—B.B. in the forceps fuses with difficulty on the edges (F. = 4·5–5), coloring the flame reddish yellow; moistened with sulphuric acid and heated colors the flame pale bluish green (phosphoric acid); some varieties react for chlorine with salt of phosphorus, when the bead has been previously saturated with copper oxide, while others give fluorine when fused with this salt in an open glass tube. Gives a phosphide with the sodium test. Dissolves in hydrochloric and nitric acids, yielding with sulphuric acid a copious precipitate of calcium sulphate; the dilute nitric acid solution gives with lead acetate a white precipitate, which B.B. on charcoal fuses, giving a globule with crystalline facets on cooling. Some varieties of apatite phosphoresce on heating.

Diff.—Characterized by the common hexagonal form, but softer than beryl, being scratched by a knife; does not effervesce in acid (like calcite); difficultly fusible; yields a green flame B.B. after being moistened with sulphuric acid.

Recognized in thin sections by its moderately high relief; extremely low birefringence (hence not often showing a distinct axial figure in basal sections), the interference colors in ordinary sections scarcely rising above gray of the first order; parallel extinction and negative extension; columnar form; lack of color and cleavage; and by the rude cross parting seen as occasional cracks crossing the prism.

Obs.—Apatite occurs in rocks of various kinds and ages, but is most common in metamorphic crystalline rocks, especially in granular limestone and in many metalliferous veins, particularly those of tin, in gneiss, syenite, hornblendic gneiss, mica schist, beds of iron ore; occasionally in serpentine. In the form of minute microscopic crystals it has an almost universal distribution as a rock-forming mineral. It is found in all kinds of igneous rocks and is one of the earliest products of crystallization. In larger crystals it is especially characteristic of the pegmatite facies of igneous rocks, particularly the granites, and occurs there associated with quartz, feldspar, tourmaline, muscovite, beryl, etc. It is sometimes present in ordinary stratified limestone, beds of sandstone or shale of the Silurian, Carboniferous, Jurassic, Cretaceous, or Tertiary. It has been observed as the petrifying material of wood.

Among its localities are Ehrenfriedersdorf in Saxony; Schwarzenstein, the Knappenwand in Untersulzbachthal in the Tyrol; St. Gothard, Tavetsch, etc., in Switzerland; Mussa-Alp in Piedmont, white or colorless; Zinnwald and Schlackenwald in Bohemia; in England, in Cornwall, with tin ores; in Cumberland, at Carrock Fells; in Devonshire, cream-colored at Bovey Tracey, and at Wheal Franco (*francolite*). The ***asparagus-stone*** or ***spargelstein*** of Jumilla, in Murcia, Spain, is pale yellowish green in color. Large quantities of apatite are mined in Norway at Kragerö; also at Ödegaard, near Bamle, and elsewhere.

In *Maine*, on Long Island, Blue-hill Bay. In *N. Hamp.*, Westmoreland. In *Mass.*, at Norwich; at Bolton abundant. In *Conn.*, at Branchville (*manganapatite*), also greenish white and colorless. In *New York*, common in St. Lawrence Co., in granular limestone; also Jefferson Co.; Sandford mine, East Moriah, Essex Co., in magnetite; near Edenville, Orange Co. In *Penn.*, at Leiperville, Delaware Co.; in Chester Co. In *N. Carolina*, at Stony Point, Alexander Co., etc.

In extensive beds in the Laurentian gneiss of Canada, usually associated with limestone, and accompanied by pyroxene, amphibole, titanite, zircon, garnet, vesuvianite and many other species. Prominent mines are in Ottawa County, Quebec, in the townships of Buckingham, Templeton, Portland, Hull, and Wakefield. Also in Renfrew county, Ontario, and in Lanark, Leeds, and Frontenac counties.

Apatite was named by Werner from ἀπατάειν, *to deceive*, older mineralogists having referred it to aquamarine, chrysolite, amethyst, fluor, schorl, etc.

Besides the definite *mineral phosphates*, including normal apatite, phosphorite, etc., there are also extensive deposits of amorphous phosphates, consisting largely of "bone phosphate" ($Ca_3P_2O_8$), of great economic importance, though not having a definite chemical composition and hence not strictly belonging to pure mineralogy. Here belong the phosphatic nodules, coprolites, bone beds, guano, etc. Extensive phosphatic deposits also occur in North Carolina, Alabama and Florida. Guano is bone phosphate of lime, mixed with the hydrous phosphates, and generally with some calcium carbonate, and often a little magnesia, alumina, iron, silica, gypsum and other impurities.

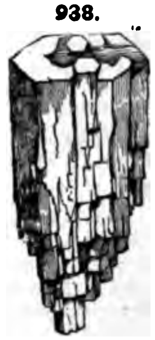
STAFFELITE. A carbonated calcium phosphate. Occurs incrusting the phosphorite of Staffel, in botryoidal or stalactitic masses, fibrous and radiating; it is the result of the action of carbonated waters. H. = 4. G. = 3·128. Color leek to dark green, greenish yellow. *Dahllite*, from Bamle, Norway, is similar.

PYROMORPHITE. Green Lead Ore. Grünbleierz *Germ.*

Hexagonal-pyramidal. Axis $\dot{c}$ = 0·7362.

Crystals prismatic, often in rounded barrel-shaped forms; also in branching groups of prismatic crystals in nearly parallel position, tapering down to a slender point. Often globular, reniform, and botryoidal or verruciform, with usually a subcolumnar structure; also fibrous, and granular.

938.



Cleavage: *m*, *x* (10$\bar{1}$1) in traces. Fracture subconchoidal, uneven. Brittle. H. = 3·5–4. G. = 6·5–7·1 mostly, when pure; 5·9–6·5, when containing lime. Luster resinous. Color green, yellow and brown, of different shades; sometimes wax-yellow and fine orange-yellow; also grayish white to milk-white. Streak white, sometimes yellowish. Subtransparent to subtranslucent. Optically –.

Var.—1. *Ordinary.* (*a*) *In crystals* as described; sometimes yellow and in rounded forms resembling campylite (*pseudo-campylite*). (*b*) In *acicular* and *moss-like* aggregations. (*c*) *Concretionary* groups or masses of crystals, having the surface angular. (*d*) *Fibrous.* (*e*) *Granular massive.* (*f*) *Earthy;* incrusting.

2. *Polysphærite.* Containing lime; color brown of different shades, yellowish gray, pale yellow to nearly white; streak white; G. = 5·89–6·44. Rarely in separate crystals; usually in groups, globular, mammillary, verruciform. *Miesite*, from Mies in Bohemia, is a brown variety. *Nussierite* is similar and impure, from Nussière, near Beaujeu, France: color yellow, greenish or grayish; G. = 5·042. 3. *Chromiferous;* color brilliant red and orange. 4. *Arseniferous;* color green to white; G. = 5·5–6·6. 5. *Pseudomorphous;* (*a*) after galena; (*b*) cerussite.

Comp.—$(PbCl)Pb_4(PO_4)_3$, or also written $3Pb_3P_2O_8.PbCl_2$ = Phosphorus pentoxide 15·7, lead protoxide 82·2, chlorine 2·6 = 100·5, or Lead phosphate 89·7, lead chloride 10·3 = 100.

The phosphorus is often replaced by arsenic, and as the amount increases the species passes into mimetite. Calcium also replaces the lead to a considerable extent.

Pyr., etc.—In the closed tube gives a white sublimate of lead chloride. B.B. in the forceps fuses easily (F. = 1·5), coloring the flame bluish green; on charcoal fuses without reduction to a globule, which on cooling assumes a crystalline polyhedral form, while the coal is coated white from chloride and, nearer the assay, yellow from lead oxide. With soda on charcoal yields metallic lead; some varieties contain arsenic, and give the odor of garlic in R.F. on charcoal. With salt of phosphorus, previously saturated with copper oxide, gives an azure-blue color to the flame when treated in O.F. (chlorine). Soluble in nitric acid.

Diff.—Distinguished by its hexagonal form; high specific gravity; resinous luster; blowpipe characters.

Obs.—Pyromorphite occurs principally in veins, and accompanies other ores of lead. At Poullaouen and Huelgoet in Brittany; at Zschopau and other places in Saxony; at Přibram, Bleistadt, in Bohemia; in fine crystals at Ems, Braubach, in Nassau; also at Dernbach in Nassau; Berezov in Siberia; in the Nerchinsk mining district; Cornwall, green and brown; Devon, gray; Derbyshire, green and yellow; Cumberland, golden yellow, in England; Leadhills, red and orange, in Scotland.

In the U. S., has been found very fine at Phenixville, Pa.; also in Maine, at Lubec and Lenox; in New York, a mile south of Sing Sing; in Davidson Co., N. C., also in Cabarrus and Caldwell Cos.

Named from *πῦρ*, *fire*, *μορφή*, *form*, alluding to the crystalline form the globule assumes on cooling. This species passes into mimetite.

MIMETITE.

Hexagonal-pyramidal. Axis $\dot{c}$ = 0·7224.

Habit of crystals like pyromorphite; sometimes rounded to globular forms. Also in mammillary crusts.

Cleavage: x $(10\bar{1}1)$ imperfect. Fracture uneven. Brittle. H. = 3·5. G. = 7·0–7·25. Luster resinous. Color pale yellow, passing into brown; orange-yellow; white or colorless. Streak white or nearly so. Subtransparent to translucent.

Var.—1. *Ordinary.* (*a*) *In crystals*, usually in rounded aggregates. (*b*) *Capillary* or filamentous, especially marked in a variety from St. Prix-sous-Beuvray, France; somewhat like asbestus, and straw-yellow in color. (*c*) *Concretionary.*

Campylite, from Drygill in Cumberland, has G. = 7·218, and is in barrel-shaped crystals (whence the name, from *καμπύλος*, *curved*), yellowish to brown and brownish red; contains 3 p. c. P_2O_5.

Comp.—$(PbCl)Pb_4(AsO_4)_3$, also written $3Pb_3As_2O_8.PbCl_2$ = Arsenic pentoxide 23·2, lead protoxide 74·9, chlorine 2·4 = 100·5, or Lead arsenate 90·7, lead chloride 9·3 = 100.

Phosphorus replaces the arsenic in part, and calcium the lead. *Endlichite* (p. 501) is intermediate between mimetite and vanadinite.

Pyr., etc.—In the closed tube like pyromorphite. B.B. fuses at 1, and on charcoal gives in R.F. an arsenical odor, and is easily reduced to metallic lead, coating the coal at first with lead chloride, and later with arsenic trioxide and lead oxide. Gives the chlorine reaction as under pyromorphite. Soluble in nitric acid.

Obs.—Occurs near Redruth and elsewhere in Cornwall; Beer Alston, Devonshire; in Cumberland; near Pontgibaud, Puy-de-Dôme; at Johanngeorgenstadt, in fine yellow crystals; at Nerchinsk, Siberia; at Zinnwald; Långban, Sweden; at the Brookdale mine, Phenixville, Pa.

Named from *μιμητής*, *imitator*, it closely resembling pyromorphite.

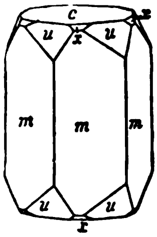
VANADINITE.

Hexagonal-pyramidal. Axis $\dot{c}$ = 0·7122.

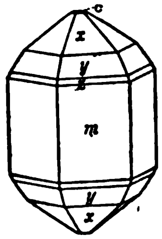
Crystals prismatic, with smooth faces and sharp edges; sometimes cavernous, the crystals hollow prisms; also in rounded forms and in parallel groupings like pyromorphite. In implanted globules or incrustations.

Fracture uneven, or flat conchoidal. Brittle. H. = 2·75–3. G. = 6·66–7·10. Luster of surface of fracture resinous. Color deep ruby-red, light brownish yellow, straw-yellow, reddish brown. Streak white or yellowish. Subtranslucent to opaque.

939.



940.



941.

Comp.—$(PbCl)Pb_4(VO_4)_3$, also written $3Pb_3V_2O_8.PbCl_2$ = Vanadium pentoxide 19·4, lead protoxide 78·7, chlorine 2·5 = 100·6, or Lead vanadate 90·2, lead chloride 9·8 = 100.

Phosphorus is sparingly present, also sometimes arsenic, both replacing vanadium. In *endlichite* the ratio of V : As = 1 : 1 nearly.

Pyr., etc.—In the closed tube decrepitates and yields a faint white sublimate. B.B. fuses easily, and on charcoal to a black lustrous mass, which in R.F. yields metallic lead and a coating of lead chloride; after completely oxidizing the lead in O.F. the black residue gives with salt of phosphorus an emerald-green bead in R.F., which becomes light yellow in O.F. Gives the chlorine reaction with the copper test. Decomposed by hydrochloric acid.

Obs.—First discovered at Zimapan in Mexico. Later obtained at Wanlockhead in Dumfriesshire; also at Berezov in the Ural, with pyromorphite; and near Kappel in Carinthia, in crystals; at Undenäs, Bölet, Sweden. In the Sierra de Córdoba, Argentine Republic.

In the U States, sparingly near Sing Sing, N. Y. Abundant in the mining regions of Arizona and New Mexico, often associated with wulfenite and descloizite; in Arizona, at the mines in Yuma Co., in brilliant deep red crystals; Vulture, Phœnix, etc., in Maricopa Co.; the Mammoth gold mine, near Oracle, Pinal Co. In New Mexico, at Lake Valley, Sierra Co. (*endlichite*); and the Mimbres mines near Georgetown.

HEDYPHANE. From Långbau, Sweden; has ordinarily been included as a calcium variety of mimetite, but is now made monoclinic. Massive, cleavable. Color yellowish white.

Svabite. A calcium arsenate, related to the species of the Apatite Group. Crystals hexagonal prisms; colorless; $\dot{c}$ = 0·7143. H. = 5. G. = 3·52. From the Harstig mine, Pajsberg, Sweden.

Wagnerite Group. Monoclinic.

		$\grave{a} : \bar{b} : \dot{c}$	β
Wagnerite	$(MgF)MgPO_4$	1·9145 : 1 : 1·5059;	71° 53′
Triplite	$(RF)RPO_4$, R = Fe : Mn = 2 : 1, 1 : 1, etc.		
Triploidite	$(ROH)RPO_4$, R = Mn : Fe = 3 : 1	1·8572 : 1 : 1·4925;	71° 46′
Adelite	$(MgOH)CaAsO_4$	2·1978 : 1 : 1·5642;	73° 15′
Tilasite	$(MgF)CaAsO_4$		
Sarkinite	$(MnOH)MnAsO_4$	2·0017 : 1 : 1·5154;	62° 13½′

Phosphates (and arsenates) of magnesium (calcium), iron and manganese containing fluorine (also hydroxyl). Formula R_2FPO_4 or $(RF)RPO_4$, etc.

WAGNERITE.

Monoclinic. Axes, see p. 501. Crystals sometimes large and coarse. Also massive.

Cleavage: *a*, *m* imperfect; *c* in traces. Fracture uneven and splintery. Brittle. H. = 5–5·5. G. = 3·07–3·14. Luster vitreous. Streak white. Color yellow, of different shades; often grayish, also flesh-red, greenish. Translucent.

Comp.—A fluo-phosphate of magnesium, $(MgF)MgPO_4$ or $Mg_3P_2O_8.MgF_2$ = Phosphorus pentoxide 43·8, magnesia 49·3, fluorine 11·8 = 104·9, deduct (O = 2F) 4·9 = 100. A little calcium replaces part of the magnesium.

Pyr., etc.—B.B. in the forceps fuses at 4 to a greenish-gray glass; moistened with sulphuric acid colors the flame bluish green. With borax reacts for iron. On fusion with soda effervesces, but is not completely dissolved; gives a faint manganese reaction. Fused with salt of phosphorus in an open glass tube reacts for fluorine. Soluble in nitric and hydrochloric acids. With sulphuric acid evolves fumes of hydrofluoric acid.

Obs.—*Wagnerite* (in small highly modified crystals) occurs in the valley of Höllengraben, near Werfen, in Salzburg, Austria. *Kjerulfine* (massive, cleavable; also in coarse crystals) is from Kjörrestad, near Bamle, Norway.

Spodiosite. A calcium fluo-phosphate, perhaps $(CaF)CaPO_4$. In flattened prismatic crystals. G. = 2·94. Color ash-gray. From the Krangrufva, Wermland, Sweden.

TRIPLITE.

Monoclinic. Massive, imperfectly crystalline. Cleavage: unequal in two directions perpendicular to each other, one much the more distinct. Fracture small conchoidal. H. = 4–5·5. G. = 3·44–3·8. Luster resinous, inclining to adamantine. Color brown or blackish brown. Streak yellowish gray or brown. Subtranslucent to opaque.

Comp., Var.—$(RF)RPO_4$ or $R_3P_2O_8.RF_2$ with R = Fe and Mn, also Ca and Mg. The ratio varies widely from Fe : Mn = 1 : 1 to 2 : 1 (zwieselite); 1 : 2; 1 : 7.

Talktriplite is a variety from Horrsjöberg; contains magnesium and calcium in large amount.

Pyr., etc.—B.B. fuses easily at 1·5 to a black magnetic globule; moistened with sulphuric acid colors the flame bluish green. With borax in O.F. gives an amethystine-colored glass (manganese); in R.F. a strong reaction for iron. With soda reacts for manganese. With sulphuric acid evolves hydrofluoric acid Soluble in hydrochloric acid.

Obs.—Found by Alluaud at Limoges in France; Helsingfors, Finland; Stoneham, Maine; Branchville, Conn. *Zwieselite*, a clove-brown variety, is from Rabenstein, near Zwiesel in Bavaria.

GRIPHITE. A problematical phosphate related to triplite occurring in embedded reniform masses. From the Riverton lode near Harney City, Pennington Co., S. Dakota.

Triploidite. Like triplite, but with the F replaced by (OH). Commonly in crystalline aggregates. Fibrous to columnar. H. = 4·5–5. G. = 3·697. Color yellowish to reddish brown. From Branchville, Fairfield Co., Conn.

Adelite. $(MgOH)CaAsO_4$. Monoclinic. Axes, see p. 501; also massive. H. = 5. G. = 3·74. Color gray or grayish yellow. From Nordmark and Långban, Sweden.

Tilasite. Like adelite, but contains fluorine. From Långban.

Sarkinite. $(MnOH)MnAsO_4$. In monoclinic crystals; also in spherical forms. G. = 4·17. Color rose-red, flesh-red, reddish yellow. From the iron-manganese mines of Pajsberg, Sweden. *Polyarsenite* from the Sjö mine, Grythytte parish, Örebro, Sweden, is essentially the same.

Herderite. A fluo-phosphate of beryllium and calcium, $(CaF)BePO_4$ with $(CaOH)BePO_4$. In prismatic crystals, monoclinic with complex twinning. H. = 5. G. = 2·99–3·01. Luster vitreous. Color yellowish and greenish white. From the tin mines of Ehrenfriedersdorf, Saxony; also at Stoneham, Auburn and Hebron, Maine.

Hamlinite. A basic phosphate of aluminium and strontium. In colorless rhombohedral crystals. H. = 4·5. G. = 3·16–3·28. Occurs with herderite, bertrandite, etc., at Stoneham, Maine.

Durangite. A fluo-arsenate of sodium and aluminium, $Na(AlF)AsO_4$. In monoclinic crystals. G. = 3·94–4·07. Color orange-red. From Durango, Mexico.

AMBLYGONITE. Hebronite.

Triclinic. Crystals large and coarse (Fig. 20, p. 10); forms rarely distinct. Usually cleavable to columnar and compact massive. Polysynthetic twinning lamellæ common.

Cleavage: *c* perfect, with pearly luster; *a* somewhat less so, vitreous; *e* (0$\bar{2}$1) sometimes equally distinct; *M* (1$\bar{1}$0) difficult; *ca* = 75° 30′, *ce* = 74° 40′, *cM* = 92° 20′. Fracture uneven to subconchoidal. Brittle. H. = 6. G. = 3·01–3·09. Luster vitreous to greasy, on *c* pearly. Color white to pale greenish, bluish, yellowish, grayish or brownish white. Streak white. Subtransparent to translucent.

Comp. — A fluo-phosphate of aluminium and lithium, $Li(AlF)PO_4$ or $AlPO_4.LiF$ = Phosphorus pentoxide 47·9, alumina 34·4, lithia 10·1, fluorine 12·9 = 105·3, deduct (O = 2F) 5·3 = 100. Sodium often replaces part of the lithium, and hydroxyl part of the fluorine.

Pyr., etc.—In the closed tube yields water, which at a high heat is acid and corrodes the glass. B.B. fuses easily (at 2) with intumescence, and becomes opaque white on cooling. Colors the flame yellowish red with traces of green; the Hebron variety gives an intense lithia-red; moistened with sulphuric acid gives a bluish green to the flame. With borax and salt of phosphorus forms a transparent colorless glass. In fine powder dissolves easily in sulphuric acid, more slowly in hydrochloric acid.

Diff.—Distinguished by its easy fusibility and by yielding a red flame B.B., from feldspar, barite, calcite, etc.; also by the acid water in the tube from spodumene.

Obs.—Occurs near Penig in Saxony; Arendal, Norway; Montebras, Creuze, France. In the U. States, in Maine, at Hebron; also at Paris, Peru, etc.; Branchville, Conn.

The name *amblygonite* is from *ἀμβλύς*, *blunt*, and *γόνυ*, *angle*.

B. Basic Phosphates.

This section includes a series of well-characterized basic phosphates, a number of which fall into the Olivinite Group. Acid phosphates are represented by one species only, the little known monetite, probably $HCaPO_4$, see p. 507.

Olivenite Group. Orthorhombic.

		$\breve{a} : \bar{b} : \acute{c}$
Olivenite	$Cu_2(OH)AsO_4$	0·9396 : 1 : 0·6726
Libethenite	$Cu_2(OH)PO_4$	0·9601 : 1 : 0·7019
Adamite	$Zn_2(OH)AsO_4$	0·9733 : 1 : 0·7158
Descloizite	$(Pb,Zn)_2(OH)VO_4$	

$\breve{a} : \bar{b} : \acute{c}$ = 0·6368 : 1 : 0·8045 or $\frac{3}{2}\breve{a} : \bar{b} : \acute{c}$ = 0·9552 : 1 : 0·8045

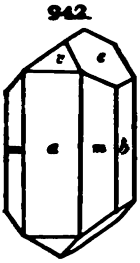
Cuprodescloizite $(Pb,Zn,Cu)_2(OH)VO_4$

The OLIVENITE GROUP includes several basic phosphates, arsenates, etc., of copper, zinc, and lead, with the general formula $(ROH)RPO_4$, $(ROH)RAsO_4$, etc. They crystallize in the orthorhombic system with similar form. It is to be noted that this group corresponds in a measure to the monoclinic Wagnerite Group, p. 501, which also includes basic members.

OLIVENITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·9396 : 1 : 0·6726$.

942.



mm''', 110 ∧ 1̄10 = 86° 26'. *ee'*, 011 ∧ 01̄1 = 67° 51'.
vv', 101 ∧ 1̄01 = 71° 11½'. *ve*, 101 ∧ 011 = 47° 38'.

Crystals prismatic, often acicular. Also globular and reniform, indistinctly fibrous, fibers straight and divergent, rarely irregular; also curved lamellar and granular.

Cleavage: *m*, *b*, *e* (011) in traces. Fracture conchoidal to uneven. Brittle. H. = 3. G. = 4·1–4·4. Luster adamantine to vitreous; of some fibrous varieties pearly. Color various shades of olive-green, passing into leek-, siskin-, pistachio-, and blackish green; also liver- and wood-brown; sometimes straw-yellow and grayish white. Streak olive-green to brown. Subtransparent to opaque.

Var.—(*a*) *Crystallized*. (*b*) *Fibrous*; finely and divergently fibrous, of green, yellow, brown and gray, to white colors, with the surface sometimes velvety or acicular; found investing the common variety or passing into it; called *wood-copper* or *wood arsenate*. (*c*) *Earthy*; nodular or massive; sometimes soft enough to soil the fingers.

Comp.—$Cu_3As_2O_8.Cu(OH)_2$ or $4CuO.As_2O_5.H_2O$ = Arsenic pentoxide 40·7, cupric oxide 56·1, water 3·2 = 100.

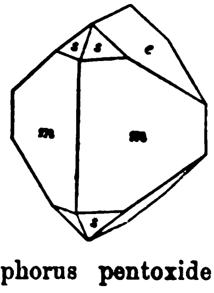
Pyr., etc.—In the closed tube gives water. B.B fuses at 2, coloring the flame bluish green, and on cooling the fused mass appears crystalline. B.B. on charcoal fuses with deflagration, gives off arsenical fumes, and yields a metallic arsenide which with soda yields a globule of copper. With the fluxes reacts for copper. Soluble in nitric acid.

Obs.—The crystallized varieties occur in Cornwall, at various mines; Tavistock, in Devonshire; in Tyrol; the Banat; Nizhni Tagilsk in the Ural; Chili. In the U. S., in Utah, at the American Eagle and Mammoth mines, Tintic district, both in crystals and *wood-copper*. The name olivenite alludes to the olive-green color.

LIBETHENITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·9601 : 1 : 0·7019$.

943.



mm''', 110 ∧ 1̄10 = 87° 40'. *ss'''*, 111 ∧ 11̄1 = 59° 4½'.
ee', 011 ∧ 01̄1 = 70° 8'. *ss'*, 111 ∧ 1̄11 = 61° 47½'.

In crystals usually small, short prismatic in habit; often united in druses. Also globular or reniform and compact.

Cleavage: *a*, *b* very indistinct. Fracture subconchoidal to uneven. Brittle. H. = 4. G. = 3·6–3·8. Luster resinous. Color olive-green, generally dark. Streak olive-green. Translucent to subtranslucent.

Comp.—$Cu_3P_2O_8.Cu(OH)_2$ or $4CuO.P_2O_5.H_2O$ = Phosphorus pentoxide 29·8, cupric oxide 66·4, water 3·8 = 100.

Pyr., etc.—In the closed tube yields water and turns black. B B. fuses at 2 and colors the flame emerald-green. On charcoal with soda gives metallic copper, sometimes also an arsenical odor. Fused with metallic lead on charcoal is reduced to metallic copper, with the formation of lead phosphate, which treated in R.F. gives a crystalline polyhedral bead on cooling. With the fluxes reacts for copper. Soluble in nitric acid.

Obs.—Occurs with chalcopyrite at Libethen, near Neusohl, Hungary; at Rheinbreitenbach and Ehl on the Rhine; at Nizhni Tagilsk in the Ural; in small quantities in Cornwall.

Adamite. $Zn_3As_2O_8.Zn(OH)_2$ In small crystals, often grouped in crusts and granular aggregations. H. = 3·5. G. = 4·34–4·35. Color honey-yellow, violet, rose-red, green, colorless. From Chañarcillo, Chili; Cap Garonne, France; at the ancient zinc mines of Laurion, Greece.

Descloizite. $R_2V_2O_8.R(OH)_2$ or $4RO.V_2O_5.H_2O$; R = Pb, Zn chiefly, and usually in the ratio 1 : 1 approx. In small crystals, often drusy; also massive, fibrous radiated with mammillary surface. H. = 3·5. G. = 5·9–6·2. Color cherry-red and brownish red, to light or dark brown, black. Streak orange to brownish red or yellowish gray.

From the Sierra de Córdoba, Argentina; Kappel in Carinthia. Abundant at Lake Valley, Sierra Co., New Mexico, also near Georgetown; in Arizona near Tombstone; in Yavapai Co.: at the Mammoth Gold mine, near Oracle, Pinal Co.

A massive variety, containing copper (6·5 to 9 p. c.), in crusts, and reniform masses with radiated structure, occurs in San Luis Potosi, also in a vein of argentiferous galena in Zacatecas, Mexico; it has been variously named *tritochorite*, *cuprodescloizite*, *ramirite*. A similar variety (11 p. c. CuO) occurs as an incrustation on quartz at the Lucky Cuss mine, Tombstone, Cochise Co., Arizona.

EUSYNCHITE may be identical with descloizite. Massive: in nodular, stalactitic forms. G. = 5·596. Color yellowish red, reddish brown, greenish. From Hofsgrund near Freiburg in Baden. The same may be true of *aræoxene* from Dahn near Nieder-Schlettenbach, Rhenish Bavaria.

DECHENITE. Composition usually accepted as PbV_2O_6. Massive, botryoidal, nodular. G. = 5·6–5·81. Color deep red to yellowish red and brownish red. From Nieder-Schlettenbach in the Lauterthal, Rhenish Bavaria.

Calciovolborthite. Probably $(Cu,Ca)_3V_2O_8.(Cu,Ca)(OH)_2$. In thin green tables; also gray, fine crystalline granular. From Friedrichsrode, Thuringia.

Brackebuschite. Near descloizite (monoclinic?). From the State of Córdoba, Argentina.

Psittacinite. A vanadate of lead and copper, from the Silver Star District, Montana. In thin coatings; also pulverulent. Color siskin- to olive-green.

MOTTRAMITE. A vanadate of lead and copper; possibly identical with psittacinite; in velvety black incrustations. From Mottram St. Andrew's, Cheshire, England.

CLINOCLASITE. Klinoklas. Aphanèse.

Monoclinic. Axes $\grave{a} : \breve{b} : \acute{c}$ = 1·9069 : 1 : 3·8507; β = 80° 30′.

Crystals prismatic (*m*); also elongated ∥ $\breve{b}$; often grouped in nearly spherical forms. Also massive, hemispherical or reniform; structure radiated fibrous.

Cleavage: *c* highly perfect. Brittle. H. = 2·5–3. G. = 4·19–4·37; 4·37 Utah. Luster: *c* pearly; elsewhere vitreous to resinous. Color internally dark verdigris-green; externally blackish blue-green. Streak bluish green. Subtransparent to translucent.

Comp.—$Cu_3As_2O_8.3Cu(OH)_2$ or $6CuO.As_2O_5.3H_2O$ = Arsenic pentoxide 30·3, cupric oxide 62·6, water 7·1 = 100.

Pyr., etc.—Same as for olivenite.

Obs.—Occurs in Cornwall, with other ores of copper. In Utah, Tintic district, at the Mammoth mine. Named in allusion to the basal cleavage being oblique to the sides of the prism.

Erinite. $Cu_3As_2O_8.2Cu(OH)_2$. In mammillated crystalline groups. Color fine emerald green. From Cornwall; also the Tintic district, Utah.

Dihydrite. $Cu_3P_2O_8.2Cu(OH)_2$ In dark emerald-green crystals (monoclinic). H. = 4·5–5. G. = 4–4·4. From Ehl near Linz on the Rhine; the Ural, etc.

Pseudomalachite. In part $Cu_3P_2O_8.3Cu(OH)_2$. Massive, resembling malachite in color and structure. From Rheinbreitenbach; Nizhni Tagilsk, etc. *Ehlite* is closely allied.

Chondrarsenite. Perhaps $Mn_3As_2O_8.3Mn(OH)_2$. In small embedded grains. Color yellow to reddish yellow. From the Pajsberg mines, Sweden.

XANTHARSENITE Near chondrarsenite, but contains more water. In sulphur-yellow grains; massive. From the Sjö mine, parish of Grythytte, Sweden.

DUFRENITE. Kraurite.

Orthorhombic. Crystals rare, small and indistinct. Usually massive, in nodules; radiated fibrous with drusy surface.

Cleavage: *a*, probably also *b*, but indistinct. H. = 3·5–4. G. = 3·2–3·4. Luster silky, weak. Color dull leek-green, olive-green, or blackish green; alters on exposure to yellow and brown. Streak siskin-green. Subtranslucent to nearly opaque. Strongly pleochroic.

Comp.—Doubtful; in part $FePO_4.Fe(OH)_3 = 2Fe_2O_3.P_2O_5.3H_2O$ = Phosphorus pentoxide 27·5, iron sesquioxide 62·0, water 10·5 = 100.

Pyr., etc.—Same as for vivianite, but less water is given out in the closed tube. B.B. fuses easily to a slag.

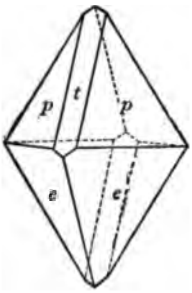
Obs.—Occurs near Anglar, Dept. of Haute Vienne, and at Hirschberg in Westphalia; from the Rothläufchen mine near Waldgirmes; St. Benigna, Bohemia; East Cornwall.

In the United States, at Allentown, N. J.; in Rockbridge Co., Va., in radiated coarsely fibrous masses.

LAZULITE.

Monoclinic: Axes $\grave{a} : \bar{b} : \acute{c}$ = 0·9750 : 1 : 1·6483; β = 89° 14′.

944.



at, 100 ∧ 101 = 30° 24′. *ee′*, $\bar{1}11 \wedge \bar{1}\bar{1}1$ = 80° 20′.
pp′, 111 ∧ $1\bar{1}1$ = 79° 40′. *pe*, 111 ∧ $\bar{1}11$ = 82° 30′.

Crystals usually acute pyramidal in habit. Also massive, granular to compact.

Cleavage: prismatic, indistinct. Fracture uneven. Brittle. H. = 5–6. G. = 3·057–3·122. Luster vitreous. Color azure-blue; commonly a fine deep blue viewed along one axis, and a pale greenish blue along another. Streak white. Subtranslucent to opaque.

Comp.—$RAl_2(OH)_2P_2O_8$ or $2AlPO_4.(Fe,Mg)(OH)_2$ with Fe : Mg(Ca) = 1 : 12, 1 : 6, 1 : 2, 2 : 3 (Rg.). For 1 : 2 the formula requires: Phosphorus pentoxide 45·4, alumina 32 6, iron protoxide 7·7, magnesia 8·5, water 5·8 = 100.

Pyr., etc.—In the closed tube whitens and yields water. B B. with cobalt solution the blue color of the mineral is restored. In the forceps whitens, cracks open, swells up, and without fusion falls to pieces, coloring the flame bluish green. The green color is made more intense by moistening the assay with sulphuric acid. With the fluxes gives an iron glass; with soda on charcoal an infusible mass. Unacted upon by acids, retaining perfectly its blue color.

Obs.—Occurs near Werfen in Salzburg; Krieglach, in Styria; also Horrsjöberg, Sweden.

Abundant with corundum at Crowder's Mt., Gaston Co., N. C.; and on Graves Mt., Lincoln Co., Ga., with cyanite, rutile, etc.

The name lazulite is derived from an Arabic word, *azul*, meaning *heaven*, and alludes to the color of the mineral.

Tavistockite. $Ca_3P_2O_3.2Al(OH)_2$. In microscopic acicular crystals, sometimes stellate groups. Color white. From Tavistock, Devonshire.

Cirrolite. Perhaps $Ca_3Al(PO_4)_3.Al(OH)_3$. Compact. G. = 3·08. Color pale yellow. Occurs at the iron mine at Westanå, in Scania, Sweden.

Arseniosiderite. $Ca_3Fe(AsO_4)_3.3Fe(OH)_3$. In yellowish brown fibrous concretions. G. = 3·520. From Romanêche, near Mâcon, France; also at Schneeberg, Saxony.

Allactite. $Mn_3As_2O_8.4Mn(OH)_2$. In small brownish-red prismatic crystals. From the Moss mine, Nordmark, and at Långban, Sweden.

Synadelphite. $2(Al.Mn)AsO_4.5Mn(OH)_2$. In prismatic crystals; also in grains. G. = 3·45–3·50. Color brownish black to black. From the Moss mine, Nordmark, Sweden.

Flinkite. $MnAsO_4.2Mn(OH)_2$. In minute orthorhombic crystals, tabular ∥ *c*; grouped in feather-like aggregates. G. = 3·87. Color greenish brown. From the Harstig mine, Pajsberg, Sweden.

Hematolite. Perhaps $(Al,Mn)AsO_4.4Mn(OH)_2$. In rhombohedral crystals. G. = 3·30–3·40. Color brownish red, black on the surface. From the Moss mine, Nordmark, Sweden.

Retzian. A basic arsenate of the yttrium earths, manganese and calcium. In orthorhombic crystals. H. = 4. G. = 4·15. Color chocolate- to chestnut-brown. From the Moss mine, Nordmark, Sweden.

Arseniopleite. Perhaps $\overset{ii}{R}_9\overset{iii}{R}_2(OH)_6(AsO_4)_6$; $\overset{ii}{R}$ = Mn, Ca, also Pb, Mg; $\overset{iii}{R}$ = Mn, also Fe. Massive, cleavable. Color brownish red. Occurs at the Sjö mine, Grythytte parish, Sweden, with rhodonite in crystalline limestone.

Manganostibiite. Hematostibiite. Highly basic manganese antimonates. In embedded grains. Color black. *Manganostibiite* occurs at Nordmark, Sweden; *hematostibiite* is from the Sjö mine, Grythytte parish.

Atelestite. Basic bismuth arsenate, $H_2Bi_3AsO_8$. In minute tabular crystals. G. = 6·4. Color sulphur-yellow. From Schneeberg, Saxony.

C. Normal Hydrous Phosphates, etc.

The only important group among the normal hydrous phosphates is the monoclinic VIVIANITE GROUP.

Struvite. Hydrous ammonium-magnesium phosphate. In orthorhombic-hemimorphic crystals (Fig. 307, p. 96); white or yellowish; slightly soluble. From guano deposits.

Collophanite. $Ca_3P_2O_8 + H_2O$. In layers resembling gymnite or opal. Colorless or snow-white. From the island of Sombrero. *Monite* is similar, from the islands Mona and Moneta in the West Indies, where it is associated with *monetite*, $HCaPO_4$, occurring in yellowish-white triclinic crystals.

PYROPHOSPHORITE. $Mg_2P_2O_7 + 4(Ca_3P_2O_8 + Ca_2P_2O_7)$. **Massive, earthy.** Color snow-white, dull. From the West Indies.

Hopeite. Probably hydrous zinc phosphate, $Zn_3P_2O_8 + H_2O$. In minute prismatic crystals. Also in reniform masses. G. = 2·76–2·85. Color grayish white. Found in cavities in calamine at the zinc mines of Altenberg, near Aix-la-Chapelle. The composition given is that of the artificial mineral.

Dickinsonite. $3R_3P_2O_8 + H_2O$ with R = Mn, Fe, Na_2 chiefly, also Ca, K_2, Li_2. In tabular, pseudo-rhombohedral crystals; commonly foliated to micaceous. G. = 3·338–3·343. Color olive- to oil-green, grass-green. From Branchville, Fairfield Co., Conn.

Fillowite. Formula as for dickinsonite and also from Branchville, but differing in angle. In granular crystalline masses. G. = 3·43. Color wax-yellow, yellowish to reddish brown, colorless.

The three following triclinic species are related in composition and may be in crystalline form.

Roselite. $(Ca,Co,Mg)_3As_2O_8 + 2H_2O$. In small crystals; often in druses and spherical aggregates. G. = 3·5–3·6. Color light to dark rose-red. From Schneeberg, Saxony.

Brandtite. $Ca_2MnAs_2O_8 + 2H_2O$. In prismatic crystals; crystals often united in radiated groups. G. = 3·671–3·672. Colorless to white. From the Harstig mine, near Pajsberg, Sweden.

Fairfieldite. A hydrous phosphate of calcium and manganese, $Ca_2MnP_2O_8 + 2H_2O$. In prismatic crystals; usually in foliated or fibrous crystalline aggregates. G. = 3·07–3·15. Color white or greenish white to pale straw-yellow. From Branchville, Fairfield Co., Conn.; Rabenstein, Bavaria (*leucomanganite*).

Messelite. $(Ca,Fe)_3P_2O_8 + 2\frac{1}{2}H_2O$. In minute tabular crystals. Colorless to brownish. From near Messel in Hesse.

Reddingite. $Mn_3P_2O_8 + 3H_2O$. In orthorhombic crystals near scorodite in angle; also granular. G. = 3·102. Color pinkish white to yellowish white. From Branchville, Conn.

Picropharmacolite. $R_3As_2O_8 + 6H_2O$, with R = Ca : Mg = 5 : 1. In small spherical forms. Color white. From Riechelsdorf; Freiberg; Joplin, Mo.

Trichalcite. $Cu_3As_2O_8 + 5H_2O$. In radiated groups, columnar; dendritic. Color verdigris-green. From the Turginsk copper mine.

Vivianite Group. Monoclinic.

Vivianite	$Fe_3P_2O_8 + 8H_2O$	$\grave{a} : \bar{b} : \acute{c} = 0{\cdot}7498 : 1 : 0{\cdot}7015$	$\beta = 75° 34'$
Symplesite	$Fe_3As_2O_8 + 8H_2O$	$0{\cdot}7806 : 1 : 0{\cdot}6812$	$72° 43'$
Bobierrite	$Mg_3P_2O_8 + 8H_2O$		
Hœrnesite	$Mg_3As_2O_8 + 8H_2O$		
Erythrite	$Co_3As_2O_8 + 8H_2O$	$0{\cdot}75 : 1 : 0{\cdot}70$	$75°$
Annabergite	$Ni_3As_2O_8 + 8H_2O$		
Cabrerite	$(Ni,Mg)_3As_2O_8 + 8H_2O$		
Köttigite	$Zn_3As_2O_8 + 8H_2O$		

The VIVIANITE GROUP includes hydrous phosphates of iron, magnesium, cobalt, nickel and zinc, all with eight molecules of water. The crystallization is monoclinic, and the angles so far as known correspond closely.

VIVIANITE.

Monoclinic. Crystals prismatic (*mm'''* = 71° 58'); often in stellate groups. Also reniform and globular; structure divergent, fibrous, or earthy; also incrusting.

Cleavage: *b* highly perfect; *a* in traces; also fracture fibrous nearly ⊥ *ć*. Flexible in thin laminæ; sectile. H. = 1·5–2. G. = 2·58–2·68. Luster, *b* pearly or metallic pearly; other faces vitreous. Colorless when unaltered, blue to green, deepening on exposure. Streak colorless to bluish white, changing to indigo-blue and to liver-brown. Transparent to translucent; opaque after exposure. Pleochroism strong.

Comp.—Hydrous ferrous phosphate, $Fe_3P_2O_8 + 8H_2O$ = Phosphorus pentoxide 28·3, iron protoxide 43·0, water 28·7 = 100.

Many analyses show the presence of iron sesquioxide due to alteration.

Pyr., etc.—In the closed tube yields neutral water, whitens, and exfoliates. B.B. fuses at 1·5, coloring the flame bluish green, to a grayish black magnetic globule. With the fluxes reacts for iron. Soluble in hydrochloric acid.

Obs.—Occurs associated with pyrrhotite and pyrite in copper and tin veins; sometimes in narrow veins with gold, traversing graywacke; both friable and crystallized in beds of clay, and sometimes associated with limonite, or bog iron ore; often in cavities of fossils or buried bones.

Occurs at St. Agnes and elsewhere in Cornwall; at Bodenmais; the gold mines of Verespatak in Transylvania. The earthy variety, sometimes called *blue iron-earth* or *native Prussian blue* (*Fer azuré*), occurs in Greenland, Carinthia, Cornwall, etc.

In N. America, in *New Jersey*, at Allentown, Monmouth Co., both crystallized, in nodules, and earthy; at Mullica Hill, Gloucester Co. (*mullicite*), in cylindrical masses. In *Virginia*, in Stafford Co. In *Kentucky*, near Eddyville. In *Canada*, with limonite at Vaudreuil.

Symplesite. Probably $Fe_3As_2O_8 + 8H_2O$. In small prismatic crystals and in radiated spherical aggregates. G. = 2·957. Color pale indigo, inclined to celandine-green. From Lobenstein in Voigtland; Hüttenberg, Carinthia.

Bobierrite. $Mg_3P_2O_8 + 8H_2O$. In aggregates of minute crystals; also massive. Colorless to white. From the guano of Mexillones, on the Chilian coast. *Hautefeuillite* is like bobierrite, but contains calcium. From Bamle, Norway.

Hœrnesite. $Mg_3As_2O_8 + 8H_2O$. In crystals resembling gypsum; also columnar; stellar-foliated. Color snow-white. From the Banat, Hungary.

ERYTHRITE. Cobalt Bloom. Kobaltblüthe *Germ.*

Monoclinic. Crystals prismatic and vertically striated. Also in globular and reniform shapes, having a drusy surface and a columnar structure; sometimes stellate. Also pulverulent and earthy, incrusting.

Cleavage: *b* highly perfect. Sectile. H. = 1·5–2·5; least on *b*. G. = 2·948. Luster of *b* pearly; other faces adamantine to vitreous; also dull, earthy. Color crimson- and peach-red, sometimes gray. Streak a little paler than the color. Transparent to subtranslucent.

Comp.—Hydrous cobalt arsenate, $Co_3As_2O_8 + 8H_2O$ = Arsenic pentoxide 38·4, cobalt protoxide 37·5, water 24·1 = 100. The cobalt is sometimes replaced by nickel, iron, and calcium.

Pyr., etc.—In the closed tube yields water at a gentle heat and turns bluish; at a higher heat gives off arsenic trioxide, which condenses in crystals on the cool glass, and the residue has a dark gray or black color. B.B. in the forceps fuses at 2 to a gray bead, and colors the flame light blue (arsenic). B.B. on charcoal gives an arsenical odor, and fuses to a dark gray arsenide, which with borax gives the deep blue color characteristic of cobalt. Soluble in hydrochloric acid, giving a rose-red solution.

Obs.—Occurs at Schneeberg in Saxony, in micaceous scales; Wolfach in Baden; Modum in Norway.

In the U. S., in Penn., sparingly near Philadelphia; in Nevada, at Lovelock's station. In California. Named from *ἐρυθρός, red.*

Annabergite. $Ni_3As_2O_8 + 8H_2O$. In capillary crystals; also massive and disseminated. Color fine apple-green. From Allemont in Dauphiné; Annaberg and Schneeberg; Riechelsdorf; in Colorado; Nevada.

Cabrerite. $(Ni,Mg)_3As_2O_8 + 8H_2O$. Like erythrite in habit. Also fibrous, radiated; reniform, granular. Color apple-green. From the Sierra Cabrera, Spain; at Laurion, Greece.

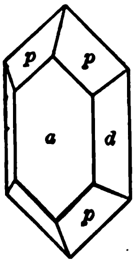
Köttigite. Hydrous zinc arsenate, $Zn_3As_2O_8 + 8H_2O$. Massive, or in crusts. Color light carmine- and peach-blossom-red. Occurs with smaltite at the cobalt mine Daniel, near Schneeberg.

Rhabdophanite. Scovillite. A hydrous phosphate of the cerium and yttrium metals. Massive, small mamillary; as an incrustation. G. = 3·94–4·01. Color brown, pinkish or yellowish white. *Rhabdophanite* is from Cornwall; *Scovillite* is from the Scoville (limonite) ore bed in Salisbury, Conn.

Churchite. A hydrous phosphate of cerium and calcium. As a thin coating of minute crystals. G. = 3·14. Color pale smoke-gray tinged with flesh-red. From Cornwall.

SCORODITE.

945.



Orthorhombic. Axes $\breve{a} : \bar{b} : \grave{c}$ = 0·8658 : 1 : 0·9541.

dd', $120 \wedge \bar{1}20 = 60^\circ\ 1'$. pp'', $111 \wedge \bar{1}\bar{1}1 = 111^\circ\ 6'$.
pp' $111 \wedge \bar{1}11 = 77^\circ\ 8'$. pp''', $111 \wedge 1\bar{1}1 = 65^\circ\ 20'$.

Habit octahedral, also prismatic. Also earthy, amorphous.

Cleavage: *d* imperfect; *a*, *b* in traces. Fracture uneven. Brittle. H. = 3·5–4. G. = 3·1–3·3. Luster vitreous to subadamantine and subresinous. Color pale leek-green or liver-brown. Streak white. Subtransparent to translucent.

Comp.—Hydrous ferric arsenate, $FeAsO_4 + 2H_2O$ = Arsenic pentoxide 49·8, iron sesquioxide 34·6, water 15·6 = 100.

Pyr., etc.—In the closed tube yields neutral water and turns yellow. B.B. fuses easily, coloring the flame blue. B.B. on charcoal gives arsenical fumes, and with soda a black magnetic scoria. With the fluxes reacts for iron. Soluble in hydrochloric acid.

Obs.—Often associated with arsenopyrite. From Schwarzenberg, Saxony; Dernbach, Nassau; Lölling, Carinthia; Nerchinsk, Siberia, in fine crystals; leek-green, in the Cornish mines.

Occurs near Edenville, N. Y., with arsenopyrite: in Utah, Tintic district, at the Mammoth mine on enargite. As an incrustation on siliceous sinter of the Yellowstone geysers.

Named from *σκόροδον*, *garlic*, alluding to the odor before the blowpipe.

Strengite. $FePO_4 + 2H_2O$. Crystals rare; in habit and angle near scorodite; generally in spherical and botryoidal forms. G. = 2·87. Color pale red. From iron mines near Giessen; also in Rockbridge Co., Va., with dufrenite.

Phosphosiderite. $2FePO_4 + 3\frac{1}{2}H_2O$. An iron phosphate near strengite, but with $3\frac{1}{2}H_2O$. From the Siegen mining district, Germany.

Barrandite $(Al,Fe)PO_4 + 2H_2O$. In spheroidal concretions, color pale shades of gray. From Bohemia.

Variscite. $AlPO_4 + 2H_2O$. Commonly in crystalline aggregates and incrustations with reniform surface. Color green. From Messbach in Saxon Voigtland; Montgomery Co., Arkansas, on quartz; in nodular masses from Utah.

Callainite. $AlPO_4 + 2\frac{1}{2}H_2O$. Massive; wax-like. Color apple- to emerald-green. From a Celtic grave in Lockmariaquer.

Zepharovichite. $AlPO_4 + 3H_2O$. Crystalline to compact. Color yellowish or grayish white. From Trenic in Bohemia.

Koninckite. $FePO_4 + 3H_2O$. In small spherical aggregates of radiating needles. Color yellow. From Richelle, Belgium.

Acid Hydrous Phosphates, etc.

PHARMACOLITE.

Monoclinic. Crystals rare. Commonly in delicate silky fibers; also botryoidal, stalactitic.

Cleavage: *b* perfect. Fracture uneven. Flexible in thin laminæ. H. = 2–2·5. G. = 2·64–2·73. Luster vitreous; on *b* inclining to pearly. Color white or grayish; frequently tinged red. Streak white. Translucent to opaque.

Comp.—Probably $HCaAsO_4 + 2H_2O$ = Arsenic pentoxide 53·3, lime 25·9, water 20·8 = 100.

Obs.—Found with arsenical ores of cobalt and silver, also with arsenopyrite; at Andreasberg in the Harz; Riechelsdorf in Hesse; Joachimsthal in Bohemia, etc. Named from *φάρμακον*, *poison*.

Haidingerite. $HCaAsO_4 + H_2O$. In minute crystal aggregates, botryoidal and drusy. G. = 2·848. Color white. From Joachimsthal with pharmacolite.

Wapplerite. $HCaAsO_4 + 3\frac{1}{2}H_2O$. In minute crystals; also in incrustations. Colorless to white. Found with pharmacolite at Joachimsthal.

Brushite. $HCaPO_4 + 2H_2O$. In small slender prisms; concretionary massive. Colorless to pale yellowish. Occurs in guano. **Metabrushite**, similarly associated, is $2HCaPO_4 + 3H_2O$.

Martinite. $H_2Ca_5(PO_4)_4 + \frac{1}{2}H_2O$. From phosphorite deposits (from guano) in the island of Curaçoa, W. Indies.

Newberyite. $HMgPO_4 + 3H_2O$. In white orthorhombic crystals. From guano of Skipton Caves, Victoria. **Hannayite**, from same locality, is a hydrous phosphate of ammonium and magnesium.

Stercorite. Microcosmic salt. $HNa(NH_4)PO_4 + 4H_2O$. Phosphorsalz *Germ.* In white crystalline masses and nodules in guano.

Hureaulite. $H_2Mn_5(PO_4)_4 + 4H_2O$. In short prismatic crystals (monoclinic). Also massive, compact, or imperfectly fibrous. Color yellowish, orange-red, rose, grayish. From Limoges, commune of Huréaux, France. In the U. States, at Branchville, Conn.

Forbesite. $H_2(Ni,Co)_2As_2O_8 + 8H_2O$. Structure fibro-crystalline. Color grayish white. From Atacama.

Basic Hydrous Phosphates, etc.

Isoclasite. $Ca_3P_2O_8.Ca(OH)_2.4H_2O$. In minute white crystals; also columnar. From Joachimsthal.

Hemafibrite. $Mn_3As_2O_8.3Mn(OH)_2 + 2H_2O$. Commonly in spherical radiated groups. Color brownish red to garnet-red, becoming black. From the Moss mine, Nordmark, Sweden.

EUCHROITE.

Orthorhombic. Habit prismatic *mm'''* = 62° 40'. Cleavage: *m*, *n* (011) in traces. Fracture small conchoidal to uneven. Rather brittle. H. = 3·5–4. G. = 3·389. Luster vitreous. Color bright emerald- or leek-green. Transparent to translucent.

Comp.—$Cu_3As_2O_8.Cu(OH)_2 + 6H_2O$ = Arsenic pentoxide 34·2, cupric oxide 47·1, water 18·7 = 100.

Obs.—Occurs in quartzose mica slate at Libethen in Hungary, in crystals of considerable size, having much resemblance to dioptase. Named from *ευχροα*, *beautiful color*.

Conichalcite. Perhaps $(Cu,Ca)_3As_2O_8.(Cu,Ca)(OH)_2 + \frac{1}{2}H_2O$. Reniform and massive, resembling malachite. Color pistachio-green to emerald-green. From Andalusia, Spain; Tintic district, Utah.

Bayldonite. $(Pb\,Cu)_3As_2O_8.(Pb,Cu)(OH)_2 + H_2O$. In mamillary concretions, drusy. Color green. From Cornwall.

Tagilite. $Cu_3P_2O_8\,Cu(OH)_2 + 2H_2O$. In reniform or spheroidal concretions; earthy. Color verdigris- to emerald-green. From the Ural.

Leucochalcite. Probably $Cu_3As_2O_8.Cu(OH)_2 + 2H_2O$. In white, silky acicular crystals. From the Wilhelmine mine in the Spessart, Germany.

Volborthite. A hydrous vanadate of copper, barium, and calcium. In small six-sided tables; in globular forms. Color olive-green, citron-yellow. From the Ural.

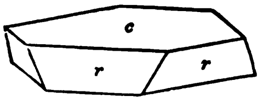
Cornwallite. $Cu_3As_2O_8.2Cu(OH)_2 + H_2O$. Massive, resembling malachite. Color emerald green. From Cornwall.

Tyrolite. Tirolit. Kupferschaum *Germ.* Perhaps $Cu_3As_2O_8.2Cu(OH)_2 + 7H_2O$. Usually in fan-shaped crystalline groups; in foliated aggregates; also massive. Cleavage perfect, yielding soft thin flexible laminæ. Color pale green inclining to sky-blue. From Libethen, Hungary; Nerchinsk, Siberia; Falkenstein, Tyrol; etc In the U. States, in the Tintic district, Utah. Some analyses yield $CaCO_3$, usually regarded as an impurity, but it may be essential.

CHALCOPHYLLITE.

Rhombohedral. Axis $\dot{c}$ = 2·5538. *cr* = 71° 16', *rr'* = 110° 12'.

946.



In tabular crystals; also foliated massive; in druses.

Cleavage: *c* highly perfect; *r* in traces. H. = 2. G. = 2·4–2·66. Luster of *c* pearly; of other faces vitreous or subadamantine. Color emerald- or grass-green to verdigris-green. Streak somewhat paler than the color. Transparent to translucent. Optically —.

Comp.—A highly basic arsenate of copper; formula uncertain, perhaps $7CuO.As_2O_5.14H_2O$.

Pyr., etc.—In the closed tube decrepitates, yields much water, and gives a residue of olive-green scales. In other respects like olivenite. Soluble in nitric acid, and in ammonia.

Obs.—From the copper mines near Redruth in Cornwall; at Sayda, Saxony; Moldawa in the Banat. In the U. States, in the Tintic district, Utah.

Veszelyite. A hydrous phospho-arsenate of copper and zinc, formula uncertain. Occurs as a greenish-blue crystalline incrustation at Morawitza, in the Banat.

WAVELLITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \acute{c}$ = 0·5049 : 1 : 0·3751. Crystals rare. Usually in aggregates, hemispherical or globular with crystalline surface, and radiated structure.

Cleavage: *p* (101) and *b* rather perfect. Fracture uneven to subconchoidal. Brittle. H. = 3·25–4. G. = 2·316–2·337. Luster vitreous, inclining to pearly and resinous. Color white, passing into yellow, green, gray, brown and black. Streak white. Translucent.

Comp.—$4AlPO_4.2Al(OH)_3 + 9H_2O$ = Phosphorus pentoxide 35·2, alumina 38·0, water 26·8 = 100. Fluorine is sometimes present, up to 2 p. c.

Pyr., etc.—In the closed tube gives off much water, the last portions of which react acid and color Brazil-wood paper yellow (fluorine), and also etch the tube. B.B. in the forceps swells up and splits into fine infusible particles, coloring the flame pale green. Gives a blue with cobalt solution. Heated with sulphuric acid gives off fumes of hydrofluoric acid, which etch glass. Soluble in hydrochloric acid, and also in caustic potash.

Obs.—From Barnstaple in Devonshire; at Zbirow in Bohemia; at Frankenberg, Saxony; Minas Geraes, Brazil, etc.

In the United States at the slate quarries of York Co., Pa.; White Horse Station, Chester Valley R. R., Pa.; Magnet Cove, Arkansas.

Fischerite. $AlPO_4.Al(OH)_3 + 2\frac{1}{2}H_2O$. In small prismatic crystals and in drusy crusts. Color green. From Nizhni Tagilsk in the Ural.

Peganite. $Al(PO_4).Al(OH)_3 + 1\frac{1}{2}H_2O$. Occurs in green crusts, of small prismatic crystals, at Striegis, near Freiberg, Saxony.

TURQUOIS. Turquoise.

Massive; amorphous or cryptocrystalline. Reniform, stalactitic, or incrusting. In thin seams and disseminated grains. Also in rolled masses.

Cleavage none. Fracture small conchoidal. Rather brittle. H. = 6. G. = 2·6–2·83. Luster somewhat waxy, feeble. Color sky-blue, bluish green to apple-green, and greenish gray. Streak white or greenish. Feebly subtranslucent to opaque.

Comp.—A hydrous phosphate of aluminium colored by a copper compound, $AlPO_4.Al(OH)_3 + H_2O$ = Phosphorus pentoxide 32·6, alumina 46·8, water 20·6 = 100. The copper salt probably has the composition $2CuO.P_2O_5.4H_2O$.

Pyr., etc.—In the closed tube decrepitates, yields water, and turns brown or black. B.B. in the forceps becomes brown and assumes a glassy appearance, but does not fuse; colors the flame green; moistened with hydrochloric acid the color is at first blue (copper chloride). With the fluxes reacts for copper. Soluble in hydrochloric acid.

Obs.—The highly prized oriental turquois occurs in narrow seams (2 to 4 or even 6 mm. in thickness) or in irregular patches in the brecciated portions of a porphyritic trachyte and the surrounding clay slate in Persia, not far from Nishâpûr, Khorassan; in the Megara Valley, Sinai; in the Kara-Tube Mts. in Turkestan, 50 versts from Samarkand.

In the U. States, occurs in the Los Cerillos Mts., 20 m. S. E. of Santa Fé, New Mexico, in a trachytic rock, a locality long mined by the Mexicans and in recent years reopened and extensively worked; in the Burro Mts., Grant Co., N. M.; pale green variety near Columbus, Nevada.

Natural turquois of inferior color is often artificially treated to give it the tint desired. Moreover, many stones which are of a fine blue when first found retain the color only so long as they are kept moist, and when dry they fade, become a dirty green, and are of little value. Much of the turquois (not artificial) used in jewelry in former centuries, as well as the present, and that described in the early works on minerals, was *bone-turquois* (called also *odontolite*, from ὀδούς, *tooth*), which is fossil bone, or tooth, colored by a phosphate of iron. Its organic origin becomes manifest under a microscope. Moreover, true turquois, when decomposed by hydrochloric acid, gives a fine blue color with ammonia, which is not true of the odontolite.

Wardite. $2Al_2O_3.P_2O_5.4H_2O$. Forms light-green or bluish-green concretionary incrustations in cavities of nodular masses of variscite from Utah. H. = 5. G. = 2·77.

Sphærite. Perhaps $4AlPO_4.6Al(OH)_3$. In globular drusy concretions. Color light gray, bluish. From near St. Benigna, Bohemia.

Liskeardite. $(Al,Fe)AsO_4.2(Al,Fe)(OH)_3 + 5H_2O$. In thin incrusting layers, white or bluish. From Liskeard, Cornwall.

Evansite. $2AlPO_4.4Al(OH)_3 + 12H_2O$. Massive; reniform or botryoidal. Colorless, or milk-white. From Zsetcznik, Hungary.

CŒRULEOLACTITE. Perhaps $3Al_2O_3.2P_2O_5.10H_2O$. Crypto-crystalline; milk-white to light copper-blue. From near Katzenellnbogen, Nassau; also East Whiteland Township, Chester Co., Penn.

Augelite. $2Al_2O_3.P_2O_5.3H_2O$. In tabular monoclinic crystals and massive. G. = 2·7. Colorless to white. From the iron mine of Westanå, Sweden. The same locality has also yielded the following aluminium phosphates.

BERLINITE. $2Al_2O_3\ 2P_2O_5.H_2O$. Compact, massive. G. = 2·64. Colorless to grayish or rose-red.

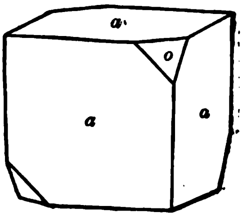
TROLLEITE. $4Al_2O_3.3P_2O_5.3H_2O$. Compact, indistinctly cleavable. G. = 3·10. Color pale green.

ATTACOLITE. $P_2O_5, Al_2O_3, MnO, CaO, H_2O$, etc.; formula doubtful. Massive. G. = 3·09. Color salmon-red.

PHARMACOSIDERITE.

Isometric-tetrahedral. Commonly in tubes; also tetrahedral. Rarely granular.

947.



Cleavage: *a* imperfect. Fracture uneven. Rather sectile. H. = 2·5. G. = 2·9–3. Luster adamantine to greasy, not very distinct. Color olive-, grass- or emerald-green, yellowish brown, honey-yellow. Streak green to brown, yellow, pale. Subtransparent to subtranslucent. Pyroelectric.

Comp.—Perhaps $6FeAsO_4.2Fe(OH)_3 + 12H_2O$ = Arsenic pentoxide 43·1, iron sesquioxide 40·0, water 16·9 = 100.

Pyr., **etc.**—Same as for scorodite.

Obs.—Obtained at the mines in Cornwall, with ores of copper; at Schneeberg and Schwarzenberg, Saxony; at Königsberg, near Schemnitz, Hungary. In Utah, at the Mammoth mine, Tintic district. Named from *φάρμακον*, *poison*, and *σίδηρος*, *iron*.

Ludlamite. $2Fe_3P_2O_8\ Fe(OH)_2 + 8H_2O$. Occurs in small green tabular crystals (monoclinic), near Truro, Cornwall.

Cacoxenite. Kakoxen *Germ.* $FePO_4.Fe(OH)_3 + 4\frac{1}{2}H_2O$. In radiated tufts of a yellow or brownish color. From near St. Benigna in Bohemia; Lancaster Co., Penn.

Beraunite. Perhaps $2FePO_4.Fe(OH)_3 + 2\frac{1}{2}H_2O$. Commonly in druses and in radiated globules and crusts. Color reddish brown to dark hyacinth-red. From St. Benigna, near Beraun, in Bohemia. *Eleonorite*, in tabular crystals, is the same mineral. From the Eleonore mine near Giessen.

GLOBOSITE, PICITE, DELVAUXITE are other hydrated ferric phosphates.

CHILDRENITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c}$ = 0·7780 : 1 : 0·52575.

mm‴, $110 \wedge 1\bar{1}0$ = 75° 46′. *rr‴*, $131 \wedge 1\bar{3}1$ = 105° 9′.
rr′, $131 \wedge \bar{1}31$ = 39° 47′. *ss′*, $121 \wedge \bar{1}21$ = 49° 56½′.

Only known in crystals. Cleavage: *a* imperfect. Fracture uneven. H. = 4·5–5. G. = 3·18–3·24. Luster vitreous to resinous. Color yellowish white, pale yellowish brown, brownish black. Streak white to yellowish. Translucent.

Comp.—In general $2AlPO_4.2Fe(OH)_2 + 2H_2O$. Phosphorus pentoxide

30·9, alumina 22·2, iron protoxide 31·3, water 15·6 = 100. Manganese replaces part of the iron and it hence graduates into eosphorite.

Pyr., etc.—In the closed tube gives off neutral water. B.B. swells up into ramifications, and fuses on the edges to a black mass, coloring the flame pale green. Heated on charcoal turns black and becomes magnetic. With soda gives a reaction for manganese. With borax and salt of phosphorus reacts for iron and manganese. Soluble in hydrochloric acid.

Obs.—From Tavistock, Devonshire. In U. States, at Hebron, Me.

Eosphorite. Form and composition as for childrenite, but containing chiefly manganese instead of iron. In prismatic crystals; also massive. Color rose-pink, yellowish, etc. From Branchville, Conn.

Mazapilite. $Ca_3Fe_2(AsO_4)_4.2FeO(OH) + 5H_2O$. In slender prismatic crystals. G. = 3·567–3·582. Color black. From Mazapil, Mexico.

Calcioferrite. $Ca_3Fe_2(PO_4)_4.Fe(OH)_3.8H_2O$. Occurs in yellow to green nodules in clay at Battenberg, Rhenish Bavaria.

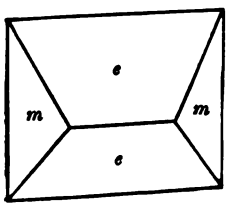
Borickite. Perhaps $Ca_3Fe_2(PO_4)_4.12Fe(OH)_3 + 6H_2O$. Reniform massive; compact. Color reddish brown. From Leoben in Styria; Bohemia.

RICHELLITE. Perhaps $4FeP_2O_8.Fe_2OF_2(OH)_2 + 36H_2O$. Massive, compact or foliated. Color yellow. From Richelle, Belgium.

LIROCONITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c} = 1·3191 : 1 : 1·6808$; $\beta = 88° 33'$.

949.



mm'', $110 \wedge 1\bar{1}0 = 105° 39'$. me', $110 \wedge 011 = 46° 10'$.
ee', $011 \wedge 0\bar{1}1 = 118° 29'$. $m'e$, $\bar{1}10 \wedge 011 = 47° 24'$.

Crystals resembling rhombic octahedrons. Rarely granular. Cleavage: *m*, *e* indistinct. Fracture subconchoidal to uneven. Imperfectly sectile. H. = 2–2·5. G. = 2·882–2·985. Luster vitreous, inclining to resinous. Color and streak sky-blue to verdigris-green.

Comp.—A hydrous arsenate of aluminium and copper, formula uncertain; analyses correspond nearly to $Cu_6Al(AsO_4)_5.3CuAl(OH)_5.20H_2O$ = Arsenic pentoxide 28·9, alumina 10·3, cupric oxide 35·9, water 24·9 = 100. Phosphorus replaces part of the arsenic.

Pyr., etc.—In the closed tube gives much water and turns olive-green. B.B. cracks open, but does not decrepitate; fuses less readily than olivenite to a dark gray slag; on charcoal cracks open, deflagrates, and gives reactions like olivenite. Soluble in nitric acid.

Obs.—From Cornwall; Herrengrund in Hungary.

Chenevixite. Perhaps $Cu_2(FeO)_2As_2O_8 + 3H_2O$. Massive to compact. Color dark green to greenish yellow. From Cornwall; Utah.

HENWOODITE. A hydrated phosphate of aluminium and copper. In botryoidal globular masses. Color turquois-blue. From Cornwall.

Chalcosiderite. $CuO\ 3Fe_2O_3.2P_2O_5.8H_2O$. In sheaf-like crystalline groups, as incrustations. Color light siskin-green. From Cornwall.

ANDREWSITE, also from Cornwall, is near chalcosiderite.

Kehoeite. A hydrated phosphate of aluminium, zinc, etc. Massive. G. = 2·34. From Galena, So. Dakota.

Goyazite. Perhaps $Ca_3Al_{10}P_2O_{23}.9H_2O$. In small rounded grains Color yellowish white. From Minas Geraes, Brazil.

Plumbogummite. A hydrated phosphate of lead and aluminium. Resembles drops or coatings of gum; as incrustations. Color yellowish, brownish. With galena at Huelgoet, Brittany, and elsewhere.

Uranite Group.

TORBERNITE. Copper Uranite. Kupferuranit *Germ.* chalcolite

Tetragonal. Axis $\dot{c}$ = 2·9361. Crystals usually square tables, sometimes very thin, again thick; less often pyramidal. Also foliated, micaceous.

Cleavage: *c* perfect, micaceous. Laminæ brittle. H. = 2–2·5. G. = 3·4–3·6. Luster of *c* pearly, other faces subadamantine. Color emerald- and grass-green, and sometimes leek-, apple-, and siskin-green. Streak paler than the color. Transparent to subtranslucent. Optically uniaxial; negative.

Comp.—A hydrous phosphate of uranium and copper, $Cu(UO_2)_2P_2O_8 + 8H_2O$ = Phosphorus pentoxide 15·1, uranium trioxide 61·2, copper 8·4, water 15·3 = 100. Arsenic may replace part of the phosphorus.

Pyr., etc.—In the closed tube yields water. In the forceps fuses at 2·5 to a blackish mass, and colors the flame green. With salt of phosphorus gives a green bead, which with tin on charcoal becomes on cooling opaque red (copper). With soda on charcoal gives a globule of copper. Soluble in nitric acid.

Obs.—From Gunnis Lake and elsewhere in Cornwall; Schneeberg, etc., Saxony; Joachimsthal, Bohemia.

Zeunerite. $Cu(UO_2)_2As_2O_8 + 8H_2O$. In tabular crystals resembling torbernite in form and color. G. = 3·2. From Schneeberg, Saxony; near Joachimsthal; Cornwall.

AUTUNITE. Lime Uranite. Kalkuranit *Germ.*

Orthorhombic. In thin tabular crystals, nearly tetragonal in form and deviating but slightly from torbernite in angle; also foliated, micaceous.

Cleavage: basal, eminent. Laminæ brittle. H. = 2–2·5. G. = 3·05–3·19. Luster of *c* pearly, elsewhere subadamantine. Color lemon- to sulphur-yellow. Streak yellowish. Transparent to translucent. Optically —. Ax. pl. ∥ *b*. Bx ⊥ *c*. β = 1·572.

Comp.—A hydrous phosphate of uranium and calcium, probably analogous to torbernite, $Ca(UO_2)_2P_2O_8 + 8H_2O$ or $CaO.2UO_3.P_2O_5.8H_2O$ = Phosphorus pentoxide 15·5, uranium trioxide 62·7, lime 6·1, water 15·7 = 100.

Some analyses give 10 and others 12 molecules of water, but it is not certain that the additional amount is essential.

Pyr., etc.—Same as for torbernite, but no reaction for copper.

Obs.—With uraninite, as at Johanngeorgenstadt, Falkenstein. In the U. States, at Middletown and Branchville, Conn. In N. Carolina, at mica mines in Mitchell Co.; in Alexander Co.; Black Hills, S. Dakota.

Uranospinite. Probably $Ca(UO_2)_2As_2O_8 + 8H_2O$. In thin tabular crystals rectangular in outline. Color siskin-green. From near Schneeberg, Saxony.

Uranocircite. $Ba(UO_2)_2P_2O_8 + 8H_2O$. In crystals similar to autunite. Color yellow-green. From Falkenstein, Saxon Voigtland.

Phosphuranylite. $(UO_2)_3P_2O_8 + 6H_2O$. As a pulverulent incrustation. Color deep lemon-yellow. From Mitchell Co., N. C.

Trögerite. $(UO_2)_3As_2O_8 + 12H_2O$. In thin druses of tabular crystals. Color lemon-yellow. From near Schneeberg, Saxony.

Walpurgite. Probably $Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$. In thin yellow crystals resembling gypsum. G. = 5·76. Color yellow. From near Schneeberg, Saxony.

Rhagite. Perhaps $2BiAsO_4.3Bi(OH)_3$. In crystalline aggregates. Color yellowish green, wax-yellow. From near Schneeberg, Saxony.

Mixite. A hydrated basic arsenate of copper and bismuth, formula doubtful. In acicular crystals; as an incrustation. Color green to whitish. From Joachimsthal; Wittichen, Baden; Tintic distr., Utah.

Antimonates; also Antimonites, Arsenites.

A number of antimonates have been included in the preceding pages among the phosphates, arsenates, etc.

Atopite. Perhaps calcium pyroantimonate, $Ca_2Sb_2O_7$. In isometric octahedrons. H. = 5·5-6. G. = 5·03. Color yellow to resin-brown. From Långban, Sweden.

Bindheimite. A hydrous antimonate of lead. Amorphous, reniform; also earthy or incrusting. Color gray, brownish, yellowish. A result of the decomposition of other antimonial ores; thus at Horhausen; in Cornwall; Sevier county, Arkansas.

Romeite. An antimonate of calcium, perhaps $CaSb_2O_4$. In groups of minute square octahedrons. H. above 5·5. G. = 4·713. Color hyacinth- or honey-yellow. From St. Marcel, Piedmont.

Nadorite. $PbClSbO_2$. In orthorhombic crystals. H. = 3·5-4. G. = 7·02. Color brownish yellow. From Djebel-Nador, Constantine, Algeria.

Ecdemite. Heliophyllite. Perhaps $Pb_4As_2O_7.2PbCl_2$. In crystals, massive, and as an incrustation. G. = 6·89-7·14. Color bright yellow to green. From Långban, Sweden; also Pajsberg (*heliophyllite*).

Ochrolite. Probably $Pb_4Sb_2O_7.2PbCl_2$. In small crystals, united in diverging groups. Color sulphur-yellow. From Pajsberg, Sweden.

Trippkeite. Essentially an arsenite of copper. In small bluish-green, tetragonal crystals. From Copiapo, Chili.

Tripuhyite. An iron antimonate. $2FeO.Sb_2O_5$. In microcrystalline aggregates of a dull greenish-yellow color. From Tripuhy, Brazil.

Derbylite. An antimo-titanate of iron. In prismatic, orthorhombic crystals. H. = 5. G. = 4·53. Color black. Tripuhy, Brazil.

Lewisite. $5CaO.2TiO_2.3Sb_2O_5$. In minute yellow to brown isometric octahedrons. Tripuhy, Brazil.

Mauzeliite. A titano-antimonate of lead and calcium, related to lewisite. In dark brown isometric octahedrons. Jakobsberg, Sweden.

AMMIOLITE. A doubtful antimonite of mercury; forming a scarlet earthy mass. From Chili.

Phosphates or Arsenates with Carbonates, Sulphates, Borates.

Staffelite and *Dahllite* (p. 499) may belong here.

Diadochite. A hydrated phosphate and sulphate of ferric iron; Thuringia. *Destinezite* is similar; from Belgium.

Pitticite. A hydrated arsenate and sulphate of ferric iron. Reniform and massive. Yellowish and reddish brown. From Saxony, Cornwall, etc.

Svanbergite. A hydrated phosphate and sulphate of aluminium and calcium. In rhombohedral crystals. Color yellow to yellowish brown, rose-red. From Horrsjöberg, Sweden.

Beudantite. A phosphate or arsenate with sulphate of ferric iron and lead; formula doubtful. In rhombohedral crystals. Color green to brown and black. From Cork; Dernbach and Horhausen, Nassau.

Lindackerite. Perhaps $3NiO.6CuO.SO_3.2As_2O_5.7H_2O$. In rosettes, and in reniform masses. Color verdigris- to apple-green. From Joachimsthal.

Lüneburgite. $3MgO.B_2O_3.P_2O_5.8H_2O$. In flattened masses, fibrous to earthy structure. From Lüneburg, Hannover.

Lossenite. A hydrous iron arsenate and lead sulphate from Laurion, Greece.

Nitrates.

The Nitrates being largely soluble in water play but an unimportant rôle in Mineralogy.

SODA NITER.

Rhombohedral. Axis $\acute{c} = 0·8276$; $rr' = 73° 30'$. Homœomorphous with calcite. Usually in massive form, as an incrustation or in beds.

Cleavage: *r* perfect. Fracture conchoidal, seldom observable. Rather sectile. H. = 1·5–2. G. = 2·24–2·29. Luster vitreous. Color white; also reddish brown, gray and lemon-yellow. Transparent. Taste cooling. Optically –. $\omega_y = 1·5874$, $\epsilon_y = 1·3361$.

Comp.—Sodium nitrate, $NaNO_3$ = Nitrogen pentoxide 63·5, soda 36·5 = 100.

Pyr., etc.—Deflagrates on charcoal with less violence than niter, causing a yellow light, and also deliquesces. Colors the flame intensely yellow. Dissolves in three parts of water at 60° F.

Obs.—From Tarapaca, northern Chili, and also the neighboring parts of Bolivia; also in Humboldt Co., Nevada; near Calico, San Bernardino Co., Cal.

Niter. Potassium nitrate, KNO_3. In thin white crusts and silky tufts.

Nitrocalcite. Hydrous calcium nitrate, $Ca(NO_3)_2 + nH_2O$. In efflorescent silky tufts and masses. In many limestone caverns, as those of Kentucky.

Nitromagnesite. $Mg(NO_3)_2 + nH_2O$. In efflorescences in limestone caves.

Nitrobarite. Barium nitrate, $Ba(NO_3)_2$. Isometric-tetartohedral. From Chili.

Gerhardtite. Basic cupric nitrate, $Cu(NO_3)_2.3Cu(OH)_2$. In pyramidal orthorhombic crystals. G. = 3·426. Color emerald-green. From the copper mines at Jerome, Arizona.

Darapskite. $NaNO_3.Na_2SO_4 + H_2O$. In square tabular crystals. Colorless. From Atacama, Chili.

Nitroglauberite. $6NaNO_3.2Na_2SO_4.3H_2O$. From Atacama.

Lautarite. Calcium iodate, $Ca(IO_3)_2$. In prismatic crystals, colorless to yellowish. From the sodium nitrate deposits of Atacama.

Dietzeite. A calcium iodo-chromate. Monoclinic; commonly fibrous or columnar. H. = 3–4. G. = 3·70. Color dark gold-yellow. From the same region as lautarite.

Oxygen Salts.

5. BORATES.

The aluminates, ferrates, etc., allied chemically to the borates, have been already introduced among the oxides. They include the species of the Spinel Group, pp. 337–341, also Chrysoberyl, p. 342, etc.

SUSSEXITE.

In fibrous seams or veins. H. = 3. G. = 3·42. Luster silky to pearly. Color white with a tinge of pink or yellow. Translucent.

Comp.—$HRBO_3$, where R = Mn, Zn and Mg = Boron trioxide 34·1, manganese protoxide, 41·5, magnesia 15·6, water 8·8 = 100. Here Mn (+ Zn) : Mg = 3 : 2.

Pyr., etc.—In the closed tube darkens in color and yields neutral water. If turmeric paper is moistened with this water, and then with dilute hydrochloric acid, it assumes a red color (boric acid). In the forceps fuses in the flame of a candle (F = 2), and B.B. in O.F. yields a black crystalline mass, coloring the flame intensely yellowish green. With the fluxes reacts for manganese. Soluble in hydrochloric acid.

Obs.—Found on Mine Hill, Franklin Furnace, Sussex Co., N. J., with franklinite, zincite, willemite, etc. An intimate mixture of zincite and calcite, not uncommon at Mine Hill, is often mistaken for sussexite, but the ready fusibility of the genuine mineral is distinctive.

Ludwigite. Perhaps $3MgO.B_2O_3 + FeO.Fe_2O_3$. In finely fibrous masses. G. = 3·91–4·02. Color blackish green to nearly black. From Morawitza, Hungary.

Pinakiolite. $3MgO.B_2O_3 + MnO.Mn_2O_3$. In small rectangular crystals. H. = 6. G. = 3·881. Luster metallic. Color black. From Långban, Sweden.

Nordenskiöldine. A calcium-tin borate, $CaSn(BO_3)_2$. In tabular rhombohedral crystals. H. = 5·5–6. G. = 4·20. Color sulphur-yellow. From the Langensund fiord, Norway.

Jeremejevite. Eichwaldite. Aluminium borate, $AlBO_3$. In prismatic hexagonal crystals. H. = 6·5. G. = 3·28. Colorless to pale yellow. From Mt. Soktuj, Adun-Chalon range in Eastern Siberia.

Hambergite. $Be_2(OH)BO_3$. In grayish-white prismatic crystals. H. = 7·5. G. = 2·347. From Langesund fiord, southern Norway.

Szaibelyite. $2Mg_5B_4O_{11}.3H_2O$. In small nodules; white outside, yellow within. From Rezbánya, Hungary.

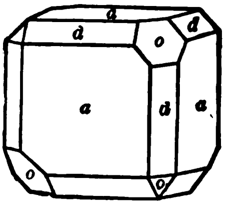
BORACITE.

Isometric and tetrahedral in external form under ordinary conditions, but in molecular structure orthorhombic and pseudo-isometric: the structure becomes isotropic, as required by the form, only when heated to 265°. (See Art. 411.)

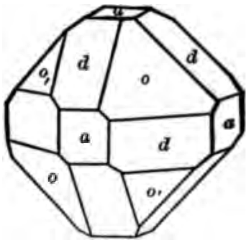
Habit cubic and tetrahedral or octahedral; also dodecahedral. Crystals usually isolated, embedded; less often in groups. Faces *o* bright and smooth, *o,* dull or uneven.

Cleavage: *o*, *o,* in traces. Fracture conchoidal, uneven. Brittle. H. = 7 in crystals. G. = 2·9–3. Luster vitreous, inclining to adamantine. Color white, inclining to gray, yellow and green. Streak white. Subtransparent to translucent. Commonly shows double refraction, which, however, disappears upon heating to 265°, when a section becomes isotropic. Refractive index, $n_y = 1·667$; $\gamma - \alpha = 0·0107$.

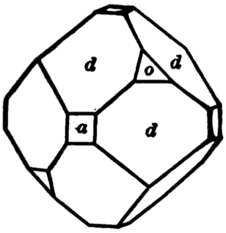
949.



950.



951.



Strongly pyroelectric, the opposite polarity corresponding to the position of the + and − tetrahedral faces (see pp. 234, 235). The faces of the dull tetrahedron $o_{,}$ (1$\bar{1}$1) form the analogous pole, those of the polished form *o* (111) the antilogous pole, Rose.

Comp.—$Mg_7Cl_2B_{16}O_{30}$ or $6MgO.MgCl_2.8B_2O_3$ = Boron trioxide 62·5, magnesia 31·4, chlorine 7·9 = 101·8, deduct (O = Cl) 1·9 = 100.

Var.—1. *Ordinary.* In crystals of varied habit. 2. *Massive*, with sometimes a subcolumnar structure; *stassfurtite* of Rose. It resembles a fine-grained white marble or granular limestone. *Parasite* of Volger is the plumose interior of some crystals of boracite. 3. *Eisenstassfurtite* contains some Fe.

Pyr., etc.—The massive variety gives water in the closed tube. B.B. both varieties fuse at 2 with intumescence to a white crystalline pearl, coloring the flame green: heated after moistening with cobalt solution assumes a deep pink color. Mixed with oxide of copper and heated on charcoal colors the flame deep azure-blue (copper chloride). Soluble in hydrochloric acid.

Alters very slowly on exposure, owing to the magnesium chloride present, which takes up water. It is the frequent presence of this deliquescent chloride in the massive mineral, thus originating, that led to the view that there was a hydrous boracite (stassfurtite). *Parasite* of Volger is a result of the same kind of alteration in the interior of crystals of boracite; this alteration giving it its somewhat plumose character, and introducing water.

Obs.—Observed in beds of anhydrite, gypsum or salt. In crystals at Kalkberg and Schildstein in Lüneburg, Hannover; at Segeberg, near Kiel, in Holstein; at Luneville, La Meurthe, France; massive, or as part of the rock, also in crystals, at Stassfurt, Prussia.

Ascharite. A hydrous magnesium borate. In white lumps with boracite. From Aschersleben, Germany.

Rhodizite. A borate of aluminium and potassium, with cæsium and rubidium. Isometric-tetrahedral; in white, translucent dodecahedrons. H. = 8. G. = 3·41. Found on red tourmaline from the vicinity of Ekaterinburg in the Ural.

Warwickite. Perhaps $6MgO.FeO.2TiO_2.3B_2O_3$. In elongated prismatic crystals. G. = 3·36. Color dark brown to dull black. From Edenville, N. Y.

Howlite. A silico-borate of calcium, $H_5Ca_2B_5SiO_{14}$. In small white rounded nodules; also earthy. From Nova Scotia.

Lagonite. $Fe_2O_3.3B_2O_3.3H_2O$. An incrustation at the Tuscan lagoons.

Larderellite. $(NH_4)_2O.4B_2O_3.4H_2O$. From the Tuscan lagoons.

COLEMANITE.

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0·7748 : 1 : 0·5410$; $\beta = 69° 5'$.

Crystals usually short prismatic ($mm''' = 72° 4'$). Massive cleavable to granular and compact.

Cleavable: *b* highly perfect; *c* distinct. Fracture uneven to subconchoidal. H. = 4–4·5. G. = 2·42. Luster vitreous to adamantine, brilliant. Colorless to milky white, yellowish white, gray. Transparent to translucent.

Comp.—$Ca_2B_6O_{11}.5H_2O$, perhaps $HCa(BO_2)_3 + 2H_2O$ = Boron trioxide 50·9, lime 27·2, water 21·9 = 100.

Pyr.—B.B. decrepitates, exfoliates, sinters, and fuses imperfectly, coloring the flame yellowish green. Soluble in hot hydrochloric acid with separation of boric acid on cooling.

Obs.—First discovered in Death Valley, Inyo Co., California; later in Calico district, San Bernardino county.

Priceite. Near colemanite. Massive, friable and chalky. Color snow-white. From Curry Co., Oregon. *Pandermite* is similar; in compact nodules from Asia Minor.

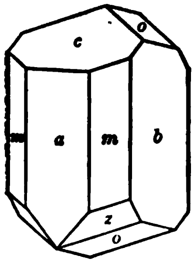
Pinnoite. $MgB_2O_4.3H_2O$. Tetragonal-pyramidal. Usually in nodules, radiated fibrous. Color sulphur- or straw-yellow. From Stassfurt.

Heintzite. Hintzeite. Kaliborite. A hydrous borate of magnesium and potassium. In small crystals, sometimes aggregated together. H. = 4–5. G. = 2·13. Colorless to white. From Leopoldshall, Stassfurt.

BORAX.

Monoclinic. Axes $\grave{a} : \bar{b} : \acute{c}$ = 1·0995 : 1 : 0·5632; β = 73° 25′.

952.



ca, 001 ∧ 100 = 73° 25′.
mm‴, 110 ∧ $1\bar{1}0$ = 93° 0′.
co, 001 ∧ $\bar{1}11$ = 40° 31′.
cs, 001 ∧ $\bar{2}21$ = 64° 8′.
oo′, $\bar{1}11$ ∧ $\bar{1}\bar{1}1$ = 57° 27′.
ss′, $\bar{2}21$ ∧ $\bar{2}\bar{2}1$ = 83° 28′.

Crystals prismatic, sometimes large; resembling pyroxene in habit and angles.

Cleavage: *a* perfect; *m* less so; *b* in traces. Fracture conchoidal. Rather brittle. H. = 2–2·5. G. = 1·69–1·72. Luster vitreous to resinous; sometimes earthy. Color white; sometimes grayish, bluish or greenish. Streak white. Translucent to opaque. Taste sweetish-alkaline, feeble. Optically −. Ax. pl. ⊥ *b*. $Bx_a \perp b$. $Bx_{o.r} \wedge \dot{c}$ = − 56° 50′. β = 1·470. $2E_r$ = 59° 30′.

Comp.—$Na_2B_4O_7.10H_2O$ or $Na_2O.2B_2O_3.10H_2O$ = Boron trioxide 36·6, soda 16·2, water 47·2 = 100.

Pyr., etc.—B.B. puffs up and afterward fuses to a transparent globule, called the glass of borax. Fused with fluorite and potassium bisulphate, it colors the flame around the assay a clear green. Soluble in water, yielding a faintly alkaline solution. Boiling water dissolves double its weight of this salt.

Obs.—Obtained from the salt lakes of Tibet; the crude mineral is called *tincal*. In California, abundant in Lake Co., at Borax Lake and Hachinhama, two small alkaline lakes in the immediate vicinity of Clear Lake; present in solution in the lake waters, and obtained also in large quantities in fine crystals embedded in the lake mud and the surrounding marshy soil; also found in fine large clear crystals at Borax Lake, San Bernardino Co.; at Death Valley, Inyo Co. Also Rhodes Marsh, etc., Esmeralda Co., Nevada.

Named borax from the Arabic *buraq*, which included also the *niter* (sodium carbonate) of ancient writers, the *natron* of the Egyptians. Borax was called chrysocolla by Agricola because used in soldering gold.

ULEXITE. Boronatrocalcite. Natronborocalcite.

Usually in rounded masses, loose in texture, consisting of fine fibers, which are acicular or capillary crystals. H. = 1. G. = 1·65. Luster silky within. Color white. Tasteless.

Comp.—A hydrous borate of sodium and calcium, probably $NaCaB_5O_9.8H_2O$ = Boron trioxide 43·0, lime 13·8, soda 7·7, water 35·5 = 100.

Pyr., etc.—Yields water. B.B. fuses at 1 with intumescence to a clear blebby glass, coloring the flame deep yellow. Moistened with sulphuric acid the color of the flame is momentarily changed to deep green. Not soluble in cold water, and but little so in hot; the solution alkaline in its reactions.

Obs.—From the dry plains of Iquique, Chili. In Nevada, in large quantities in the salt marshes of the Columbus Mining District, Esmeralda Co.

Named after the German chemist, G. L. Ulex.

Bechilite. $CaB_4O_7.4H_2O$. In crusts, as a deposit from springs in Tuscany.

Hydroboracite. $CaMgB_6O_{11}.6H_2O$. Resembles fibrous and foliated gypsum; color white. From the Caucasus.

Sulfoborite. $3MgSO_4.2Mg_3B_4O_9 + 12H_2O$. In colorless prismatic orthorhombic crystals. H. = 4. G. = 2·38–2·45. From Westeregeln, Germany.

Uranates.

URANINITE. Cleveite. Bröggerite. Nivenite. Uranpecherz *Germ.*

Isometric. In octahedrons, also with dodecahedral faces (*d*); less often in cubes with *o* and *d*. Crystals rare. Usually massive and botryoidal; also in grains; structure sometimes columnar, or curved lamellar.

Fracture conchoidal to uneven. Brittle. H. = 5·5. G. = 9·0 to 9·7 of crystals; of massive altered forms from 6·4 upwards. Luster submetallic, to greasy or pitch-like, and dull. Color grayish, greenish, brownish, velvet-black. Streak brownish black, grayish, olive-green, a little shining. Opaque.

Comp.—A uranate of uranyl, lead, usually thorium (or zirconium), often the metals of the lanthanum and yttrium groups; also containing the gases nitrogen, helium and argon, in varying amounts up to 2·6 p. c. Calcium and water (essential ?) are present in small quantities; iron also, but only as an impurity. The relation between the bases varies widely and no definite formula can be given.

Var.—The minerals provisionally included under the name uraninite are as follows:

1. *Crystallized.* *Uranniobite* from Norway. In crystals, usually octahedral, with G. varying for the most part from 9·0 to 9·7; occurs as an original constituent of coarse granites. The variety from Branchville, which is as free from alteration as any yet examined, contains chiefly UO_2 with a relatively small amount of UO_3. Thoria is prominent, while the earths of the lanthanum and yttrium groups are only sparingly represented.

Bröggerite, as analyzed by Hillebrand, gives the oxygen ratio of UO_3 to other bases of about 1 : 1; it occurs in octahedral crystals, also with *d* and *a*. G. = 9·03.

Cleveite and *nivenite* contain UO_3 in larger amount than the other varieties mentioned, and are characterized by containing about 10 p. c. of the yttrium earths. Cleveite is a variety from the Arendal region occurring in cubic crystals modified by the dodecahedron and octahedron. G. = 7·49. It is particularly rich in the gas helium. Nivenite occurs massive, with indistinct crystallization. Color velvet-black. H. = 5·5. G. = 8·01. It is more soluble than other kinds of uraninite, being completely decomposed by the action for one hour of very dilute sulphuric acid at 100°.

2. *Massive*, probably amorphous. Pitchblende. Uranpecherz *Germ.* Contains no thoria; the rare earths also absent. Water is prominent and the specific gravity is much lower, in some cases not above 6·5; these last differences are doubtless largely due to alteration. Here belong the kinds of pitchblende which occur in metalliferous veins, with sulphides of silver, lead, cobalt, nickel, iron, zinc, copper, as that from Johanngeorgenstadt, Přibram, etc.; probably also that from Black Hawk, Colorado (Hillebrand).

Pyr., etc.—B.B. infusible, or only slightly rounded on the edges, sometimes coloring the outer flame green (copper). With borax and salt of phosphorus gives a yellow bead in O.F., becoming green in R.F. (uranium). With soda on charcoal gives a coating of lead oxide, and frequently the odor of arsenic. Many specimens give reactions for sulphur and arsenic in the open tube. Soluble in nitric and sulphuric acids; the solubility differs widely in different varieties, being greater in those kinds containing the rare earths. Not attractable by the magnet.

Obs.—As noted above, uraninite occurs either as a primary constituent of granitic rocks or as a secondary mineral with ores of silver, lead, copper, etc. Under the latter condition it is found at Johanngeorgenstadt, Marienberg, and Schneeberg in Saxony, at Joachimsthal and Přibram in Bohemia, and Rezbánya in Hungary. Occurs in Norway in pegmatite veins at several points near Moss, viz.: Anneröd (*bröggerite*), Elvestad, etc.; also near Arendal at the Garta feldspar quarry (*cleveite*), associated with orthite, fergusonite, thorite, etc.

In the U. States, at the Middletown feldspar quarry, Conn., in large octahedrons, rare; at Hale's quarry in Glastonbury, a few miles N.E. of Middletown. At Branchville, Conn., in a pegmatite vein, as small octahedral crystals, embedded in albite. In N. Carolina, at the Flat Rock mine and other mica mines in Mitchell Co., rather abundant, but usually altered, in part or entirely, to gummite and uranophane; the crystals are sometimes an inch or more across and cubic in habit. In S. Carolina, at Marietta. In Texas, at the gadolinite locality in Llano Co. (*nivenite*). In large quantities at Black Hawk, near Central City, Colorado. Rather abundant in the Bald Mountain district, Black Hills, S. Dakota. Also with monazite, etc., at the Villeneuve mica veins, Ottawa Co., Quebec, Canada.

Gummite. An alteration-product of uraninite of doubtful composition. In rounded or flattened pieces, looking much like gum. G. = 3·9–4·20. Luster greasy. Color reddish yellow to orange-red, reddish brown. From Johanngeorgenstadt, also Mitchell Co., N. C.

YTTROGUMMITE. Occurs with cleveite as a decomposition-product.

THOROGUMMITE. Occurs with fergusonite, cyrtolite, and other species at the gadolinite locality in Llano Co., Texas.

Uranosphærite. $(\mathrm{BiO})_2\mathrm{U}_2\mathrm{O}_7.3\mathrm{H}_2\mathrm{O}$. In half-globular aggregated forms. Color orange-yellow, brick-red. From near Schneeberg, Saxony.

Oxygen Salts.

6. SULPHATES, CHROMATES, TELLURATES.

A. Anhydrous Sulphates, etc.

The important BARITE GROUP is the only one among the anhydrous sulphates and chromates.

Mascagnite. Ammonium sulphate, $(NH_4)_2SO_4$. Usually in crusts and stalactitic forms. Occurs about volcanoes, as at Etna, Vesuvius, etc.

Taylorite. $5K_2SO_4.(NH_4)_2SO_4$. In small compact lumps or concretions. From the guano of the Chincha Islands.

Thenardite. Anhydrous sodium sulphate, Na_2SO_4. In orthorhombic crystals, pyramidal, short prismatic or tabular; also as twins (Fig. 846, p. 118). White to brownish. Soluble in water. Often observed in connection with salt lakes, as on the shores of Lake Balkhash, Central Asia; similarly elsewhere; also in S. America in Tarapaca. In the U. S. forms extensive deposits on the Rio Verde, Arizona. In California, at Borax Lake, San Bernardino Co.

Aphthitalite. Arcanite, $(K,Na)_2SO_4$. Rhombohedral; also massive, in crusts. Color white. From Vesuvius, upon lava; at Douglashall near Westeregeln in blödite; Rocalmuto, Sicily.

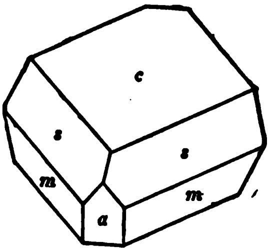
GLAUBERITE.

Monoclinic. Axes $\grave{a} : \dot{b} : \grave{c} = 1{\cdot}2200 : 1 : 1{\cdot}0275$; $\beta = 67° 49'$.

ca, 001 ∧ 100 = 67° 49'. cs, 001 ∧ 111 = 48° 2'.

mm''', 111 ∧ $1\bar{1}1$ = 96° 58'. cm, 001 ∧ 110 = 75° 30½'.

953.



In crystals tabular ‖ c; also prismatic.

Cleavage: c perfect. Fracture conchoidal. Brittle. H. = 2·5–3. G. = 2·7–2·85. Luster vitreous. Color pale yellow or gray; sometimes brick-red. Streak white. Taste slightly saline. On the optical properties (see p. 225).

Comp.—$Na_2SO_4.CaSO_4$ = Sulphur trioxide 57·6, lime 20·1, soda 22·3 = 100; or, Sodium sulphate 51·1, calcium sulphate 48·9 = 100.

Pyr., etc.—B.B. decrepitates, turns white, and fuses at 1·5 to a white enamel, coloring the flame intensely yellow. On charcoal fuses in O.F. to a clear bead; in R.F. a portion is absorbed by the charcoal, leaving an infusible hepatic residue. Soluble in hydrochloric acid. In water it loses its transparency, is partially dissolved, leaving a residue of calcium sulphate, and in a large excess this is completely dissolved.

Obs.—In crystals in rock salt at Villa Rubia, in New Castile, Spain; also at Aussee, Upper Austria; Berchtesgaden, Bavaria; Westeregeln; Stassfurt. In crystals in the Rio Verde Valley, Arizona, with thenardite, mirabilite, etc.; Borax lake, San Bernardino Co., California.

Langbeinite. $K_2Mg_2(SO_4)_3$. Isometric-tetartohedral. In highly modified colorless crystals. G. = 2·83. From Westeregeln, Germany.

Barite Group. RSO_4. Orthorhombic.

		$m \wedge m'''$ $110 \wedge 1\bar{1}0$	dd' $102 \wedge \bar{1}02$	oo' $011 \wedge 0\bar{1}1$	$\breve{a} : \bar{b} : \acute{c}$
Barite	$BaSO_4$	78° 22½′	77° 43′	105° 26′	0·8152 : 1 : 1·3136
Celestite	$SrSO_4$	75° 50′	78° 49′	104° 0′	0·7790 : 1 : 1·2801
Anglesite	$PbSO_4$	76° 16½′	78° 47′	104° 24½′	0·7852 : 1 : 1·2894
Anhydrite	$CaSO_4$	(83° 33′)	(58° 31′)	(90° 3′)	0·8933 : 1 : 1·0008

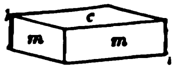
The BARITE GROUP includes the sulphates of barium, strontium, and lead, three species which are closely isomorphous, agreeing not only in axial ratio but also in crystalline habit and cleavage. With these is also included calcium sulphate, anhydrite, which has a related but not closely similar form; it differs from the others conspicuously in cleavage. It is to be noted that the carbonates of the same metals form the isomorphous ARAGONITE GROUP, p. 353.

BARITE. Heavy Spar. Barytes. Schwerspath *Germ.*

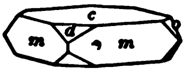
Orthorhombic. Axes $\breve{a} : \bar{b} : \acute{c}$ = 0·8152 : 1 : 1·3136.

mm''', $110 \wedge 1\bar{1}0$ = 78° 22½′.
cd, $001 \wedge 102$ = 38° 51½′.
co, $001 \wedge 01\bar{1}$ = 52° 43′.
dd'', $102 \wedge 10\bar{2}$ = 102° 17′.
oo''', $011 \wedge 01\bar{1}$ = 74° 34′.
cz, $001 \wedge 111$ = 64° 19′.

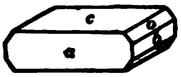
954.



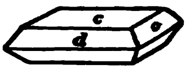
955.



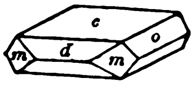
956.



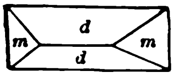
957.



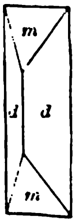
958.



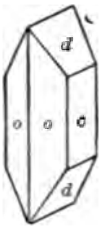
959.



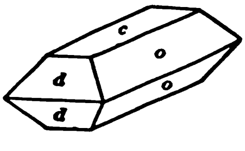
960.



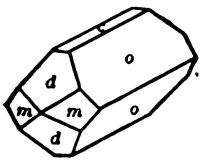
961.



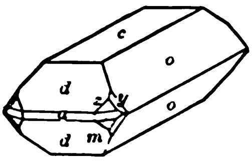
962.



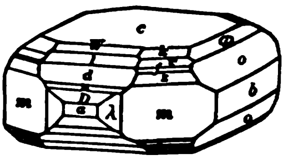
963.



964.



965.



Crystals commonly tabular ‖ c, and united in diverging groups having the axis $\bar{b}$ in common; also prismatic, most frequently ‖ axis $\bar{b}$, d (102) predominating; also ‖ axis $\acute{c}$, m prominent; again ‖ $\breve{a}$, with o (011) prominent. Also in globular forms, fibrous or lamellar, crested; coarsely laminated, laminæ convergent and often curved; granular, resembling white marble, and earthy; colors sometimes banded as in stalagmite.

Cleavage: *c* perfect; *m* also perfect, Fig. 954 the form yielded by cleavage; also *b* imperfect. Fracture uneven. Brittle. H. = 2·5–3·5. G. = 4·3–4·6; 4·489 cryst. Luster vitreous, inclining to resinous; sometimes pearly on *c*, less often on *m*. Streak white. Color white; also inclining to yellow, gray, blue, red, or brown, dark brown. Transparent to translucent to opaque. Sometimes fetid, when rubbed. Optically +. Ax. pl. ∥ *b*. Bx ⊥ *a*. $2E_r = 63° 5'$, $\beta_y = 1·6371$, (see further p. 224).

Var.—*Ordinary.* (*a*) Crystals usually broad or stout; sometimes very large; again in slender needles. (*b*) *Crested;* massive aggregations of tabular crystals, the crystals projecting at surface into crest-like forms. (*c*) *Columnar;* the columns often coarse and loosely aggregated, and either radiated or parallel; rarely fine fibrous. (*d*) In globular or nodular concretions, subfibrous or columnar within. *Bologna Stone* (from near Bologna) is here included; it was early a source of wonder because of the phosphorescence it exhibited after heating with charcoal. "Bologna phosphorus" was made from it. (*e*) Lamellar, either straight or curved; the latter sometimes as aggregations of curved scale-like plates. (*f*) Granular. (*g*) Compact or cryptocrystalline. (*h*) Earthy. (*i*) Stalactitic and stalagmitic; similar in structure and origin to calcareous stalactites and stalagmites and of much beauty when polished. (*h*) *Fetid;* so called from the odor given off when struck or when two pieces are rubbed together, which odor may be due to carbonaceous matters present.

The barite of Muzsaj, Hungary, and of Betler, near Rosenau, was early called *Wolnyn*. *Cawk* is the ordinary barite of the Derbyshire lead mines. *Dreelite*, supposed to be rhombohedral, is simply barite. *Michel-lévyte* from Perkin's Mill, Templeton, Quebec (described as monoclinic), is peculiar in its pearly luster on *m*, twinning striations, etc.

Comp.—Barium sulphate, $BaSO_4$ = Sulphur trioxide 34·3, baryta 65·7 = 100.

Strontium sulphate is often present, also calcium sulphate; further, as impurities, silica, clay, bituminous or carbonaceous substances.

Pyr., etc.—B.B. decrepitates and fuses at 3, coloring the flame yellowish green; the fused mass reacts alkaline with test paper. On charcoal reduced to a sulphide. With soda gives at first a clear pearl, but on continued blowing yields a hepatic mass, which spreads out and soaks into the coal. This reacts for sulphur (p. 262). Insoluble in acids.

Diff.—Characterized by high specific gravity (higher than celestite, aragonite, albite, calcite, gypsum, etc.); cleavage; insolubility; *green* coloration of the blowpipe flame. Albite is harder and calcite effervesces with acid.

Obs.—Occurs commonly in connection with beds or veins of metallic ores, especially of lead, also copper, silver, cobalt, manganese, as part of the gangue of the ore; also often accompanies stibnite. Sometimes present in massive forms with hematite deposits. It is met with in secondary limestones and sandstones, sometimes forming distinct veins, and in the former often in crystals along with calcite and celestite; in the latter often with copper ores. Sometimes occupies the cavities of amygdaloidal basalt, porphyry, etc.; forms earthy masses in beds of marl. Occurs as the petrifying material of fossils and occupying cavities in them.

Fine crystals are obtained at the Dufton lead mines, Westmoreland, England; also in Cumberland and Lancashire; in Derbyshire, Staffordshire, etc.; Cleator Moor; Alston Moor. In Scotland, in Argyleshire, at Strontian. Some of the most important of the many European localities are Felsöbánya, Nagybánya, Schemnitz, and Kremnitz, in Hungary, often with stibnite; Hüttenberg, Carinthia; Freiberg, Marienberg, in Saxony; Clausthal in the Harz; Přibram, Bohemia; with the manganese ores of Ilefeld, Œhrenstock, etc.; Auvergne.

In the U. States, formerly in *Conn.*, at Cheshire, intersecting the red sandstone in veins with chalcocite and malachite. In *N. York*, at Pillar Point, opposite Sackett's Harbor, massive; at Scoharie, fibrous; in St. Lawrence Co., crystals at De Kalb; the crested variety at Hammond. In *Penn.*, in crystals at Perkiomen lead mine. In *Virginia*, at Eldridge's gold mine in Buckingham Co. In *N. Carolina*, white massive at Crowders Mt., Gaston Co., etc. In *Tenn.*, on Brown's Creek; at Haysboro', near Nashville; in large veins in sandstone on the W. end of I. Royale, L. Superior, and on Spar Id., N. shore. In *Missouri*, not uncommon with the lead ores; in concretionary forms at Salina, Saline Co., Kansas. In *Colorado*, at Sterling, Weld Co.; Apishapa Creek; also in El Paso and Fremont Cos. In fine crystals, near Fort Wallace, New Mexico.

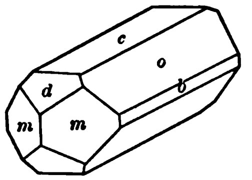
In Ontario, in Bathurst, and N. Burgess, Lanark Co.; Galway, Peterborough Co.; as large veins on Jarvis, McKellars, and Pie islands, in L. Superior, and near Fort William, Thunder Bay. In Nova Scotia, in veins in the slates of East River of the Five Islands, Colchester Co.

Named from βαρύς, *heavy*.

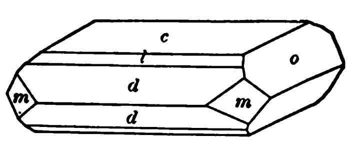
CELESTITE. Cœlestine.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}7790 : 1 : 1{\cdot}2800$.

966.



967.



mm‴, 110 ∧ 1$\bar{1}$0 = 75° 50′. *cd*, 001 ∧ 102 = 39° 24½′.
cl, 001 ∧ 104 = 22° 20′. *co*, 001 ∧ 011 = 52° 0′.

Crystals resembling those of barite in habit; commonly tabular ∥ *c* or prismatic ∥ axis *ă* or *b̄*; also more rarely pyramidal by the prominence of the forms *ψ* (133) or *χ* (144). Also fibrous and radiated; sometimes globular; occasionally granular.

Cleavage: *c* perfect; *m* nearly perfect; *b* less distinct. Fracture uneven. H. = 3–3·5. G. = 3·95–3·97. Luster vitreous, sometimes inclining to pearly. Streak white. Color white, often faint bluish, and sometimes reddish. Transparent to subtranslucent. Optically +. Ax. pl. ∥ *b*. Bx ⊥ *a*. $2E_y = 89° 36'$. $\beta_y = 1{\cdot}6237$.

Var.—1. *Ordinary.* (*a*) In crystals of varied habit as noted above; a tinge of a delicate blue is very common and sometimes belongs to only a part of a crystal. The variety from Montmartre, called *apotome*, is prismatic by extension of *o* (011) and doubly terminated by the pyramid *ψ* (133). (*b*) Fibrous, either parallel or radiated. (*c*) Lamellar; of rare occurrence. (*d*) Granular. (*e*) Concretionary. (*f*) Earthy; impure usually with carbonate of lime or clay.

Comp.—Strontium sulphate = $SrSO_4$ = Sulphur trioxide 43·6, strontia 56·4 = 100. Calcium and barium are sometimes present.

Pyr., etc.—B.B. frequently decrepitates, fuses at 3 to a white pearl, coloring the flame strontia-red; the fused mass reacts alkaline. On charcoal fuses, and in R.F. is converted into a difficultly fusible hepatic mass; this treated with hydrochloric acid and alcohol gives an intensely red flame. With soda on charcoal reacts like barite. Insoluble in acids.

Diff.—Characterized by form, cleavage, high specific gravity, *red* coloration of the blowpipe flame. Does not effervesce with acids like the carbonates (e.g., strontianite); specific gravity lower than that of barite.

Obs.—Usually associated with limestone, or sandstone of various ages; occasionally with metalliferous ores, as with galena and sphalerite at Condorcet, France; at Rezbánya, Hungary; also in beds of gypsum, rock salt, as at Bex, Switzerland, Ischl, Austria, Luneberg, Hannover; sometimes fills cavities in fossils, e.g., ammonites; with sulphur in some volcanic regions as at Girgenti, Sicily.

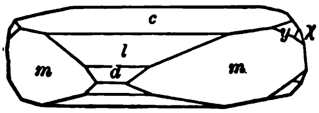
Specimens, finely crystallized, of a bluish tint, are found in limestone about Lake Huron, particularly on Drummond Island, also on Strontian Is., Put-in-Bay, L. Erie, and at Kingston in Ontario, Canada; Chaumont Bay, L. Ontario, Schoharie, and Lockport, N. Y. A blue fibrous celestite occurs at Bell's Mills, Blair Co., Penn. In Mineral Co., W. Virginia, a few miles south of Cumberland, Md., in pyramidal blue crystals. In Texas, at Lampasas, large crystals. With colemanite at Death Valley, San Bernardino Co., California. In Canada, in crystalline masses at Kingston, Frontenac Co.; Lansdowne, Leeds Co.; in radiating fibrous masses in the Laurentian of Renfrew Co.

Named from *cœlestis*, *celestial*, in allusion to the faint shades of blue often present.

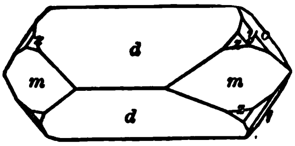
ANGLESITE. Bleivitriol, Vitriolbleierz *Germ.*

Orthorhombic. Axes $\breve{a} : \bar{b} : \acute{c} = 0·7852 : 1 : 1·2894$.

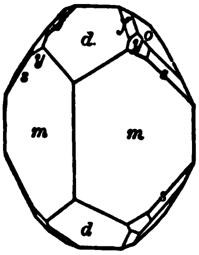
968.



969.



970.



mm''', $110 \wedge 1\bar{1}0 = 76° 16\tfrac{1}{2}'$ cd, $001 \wedge 102 = 39° 23'$.
cl, $001 \wedge 104 = 22° 19'$. co, $001 \wedge 011 = 52° 12'$.

Crystals sometimes tabular ∥ *c*; more often prismatic in habit, and in all the three axial directions, *m*, *d*, *o*, predominating in the different cases; pyramidal of varied types. Also massive, granular to compact; stalactitic; nodular.

Cleavage: *c*, *m* distinct, but interrupted. Fracture conchoidal. Very brittle. H. = 2·75–3. G. = 6·3–6·39. Luster highly adamantine in some specimens, in others inclining to resinous and vitreous. Color white, tinged yellow, gray, green, and sometimes blue. Streak uncolored. Transparent to opaque. Optically +. Ax. pl. ∥ *b*. Bx ⊥ *a*. $2H_{a.y} = 89° 52'$, Dx. Indices measured by Arzruni:

	α	β	γ	2V	2V (calc.)
For C at 20°	1·86981	1·87502	1·88630		
D "	1·87709	1·88226	1·89365	75° 24′	68°
F "	1·89549	1·90097	1·91263		
D at 50°	1·87636	1·88166	1·89281	77° 40′	69½°
" 100°	1·87529	1·88080	1·89184	82° 44′	72°
" 200°	1·87260	1·87833	1·88754	89° 17′	77°

Comp.—Lead sulphate, $PbSO_4$ = Sulphur trioxide 26·4, lead oxide 73·6 = 100.

Pyr., etc.—B.B. decrepitates, fuses in the flame of a candle (F. = 1·5). On charcoal in O.F. fuses to a clear pearl, which on cooling becomes milk-white; in R.F. is reduced with effervescence to metallic lead. With soda on charcoal in R.F. gives metallic lead, and the soda is absorbed by the coal. Difficultly soluble in nitric acid.

Diff.—Characterized by high specific gravity: adamantine luster; cleavage; and by yielding lead B.B. Cerussite effervesces in nitric acid.

Obs.—A result of the decomposition of galena, and often found in its cavities; also surrounds a nucleus of galena in concentric layers. First found in England at Pary's mine in Anglesea; at Leadhills; in Derbyshire and in Cumberland in crystals; Clausthal, in the Harz; near Siegen in Prussia; Schapbach and Badenweiler in Baden; Felsöbánya and elsewhere in Hungary; Nerchinsk, Siberia; and at Monte Poni, Sardinia; Granada; massive in Siberia, Andalusia; in Australia, whence it is exported to England. In the Sierra Mojada, Mexico, in immense quantities, mostly massive.

In the United States in crystals at Wheatley's mine, Phenixville, Pa.; in Missouri lead mines; in crystals of varied habit at the Mountain View mine, Carroll Co., Maryland. In

Colorado at various points, but less common than cerussite. At the Cerro Gordo mines of California (argentiferous galena), with other lead minerals. In Arizona, in the mines of the Castle Dome district, Yuma Co., and elsewhere.

Named from the locality, Anglesea, where it was first found.

ANHYDRITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·8933 : 1 : 1·0008$.

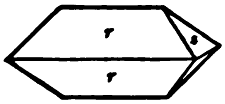
mm''', $110 \wedge 1\bar{1}0 = 83° 33'$ ee', $011 \wedge 0\bar{1}1 = 90° 3'$

rr', $101 \wedge \bar{1}01 = 96° 30'$ bo, $010 \wedge 111 = 56° 19'$

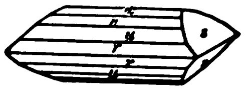
Twins: 1, tw. pl. *d* (012); 2, *r* (101) occasionally as tw. lamellæ. Crystals not common, thick tabular, also prismatic ‖ axis *b*. Usually massive, cleavable, fibrous, lamellar, granular, and sometimes impalpable.

Cleavage: in the three pinacoidal directions yielding rectangular fragments but with varying ease, thus, *c* very perfect; *b* also perfect; *a* somewhat less so. Fracture uneven, sometimes splintery. Brittle. H. = 3–3·5. G. = 2·899–2·985.

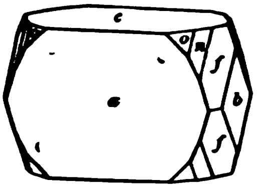
971.



972.



973.



971, 972, Stassfurt, Hbg. 973, Aussee, Id.

Luster: *c* pearly, especially after heating in a closed tube; *a* somewhat greasy; *b* vitreous; in massive varieties, vitreous inclining to pearly. Color white, sometimes a grayish, bluish, or reddish tinge; also brick-red. Streak grayish white. Optically +. Ax. pl. ‖ *b*. Bx ⊥ *a*. $2E_r = 70$. $\beta = 1·576$.

Var.—1. *Ordinary.* (*a*) Crystallized; crystals rare, more commonly massive and cleavable in its three rectangular directions. (*b*) Fibrous; either parallel, radiated or plumose. (*c*) Fine granular. (*d*) Scaly granular. *Vulpinite* is a scaly granular kind from Vulpino in Lombardy; it is cut and polished for ornamental purposes. A kind in contorted concretionary forms is the tripestone (*Gekrösstein* or *Schlangenalabaster*).

2. *Pseudomorphous*; in cubes after rock-salt.

Comp.—Anhydrous calcium sulphate, $CaSO_4$ = Sulphur trioxide 58·8, lime 41·2 = 100.

Pyr., **etc.**—B.B. fuses at 3, coloring the flame reddish yellow, and yielding an enamel-like bead which reacts alkaline. On charcoal in R.F. reduced to a sulphide; with soda does not fuse to a clear globule, and is not absorbed by the coal like barite; is, however, decomposed, and yields a mass which blackens silver. Soluble in hydrochloric acid.

Diff.—Characterized by its cleavage in three rectangular directions (pseudo-cubic in aspect); harder than gypsum; does not effervesce with acids like the carbonates.

Obs.—Occurs in rocks of various ages, especially in limestone strata, and often the same that contain ordinary gypsum, and also very commonly in beds of rock-salt; at the salt mine near Hall in Tyrol; of Bex, Switzerland; at Aussee, crystallized and massive; Lüneburg, Hannover; Kapnik in Hungary; Wieliczka in Poland; Ischl in Upper Austria; Berchtesgaden in Bavaria; Stassfurt, in fine crystals, embedded in kieserite; in cavities in lava at Santorin.

In the U. States, at Lockport, N. Y., fine blue, in geodes of black limestone, with calcite and gypsum; in limestone at Nashville, Tenn., etc. In Nova Scotia it forms extensive beds.

Anhydrite by absorption of moisture changes to gypsum. Extensive beds are sometimes thus altered in part or throughout, as at Bex, in Switzerland, where, by digging down 60 to 100 ft., the unaltered anhydrite may be found. Sometimes specimens of anhydrite are altered between the folia or over the exterior.

Zinkosite. $ZnSO_4$. Reported as occurring at a mine in the Sierra Almagrera, Spain.

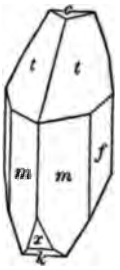
Hydrocyanite. $CuSO_4$. Found at Vesuvius as a pale green to blue incrustation after the eruption of 1868.

CROCOITE. Rothbleierz, *Germ.*

Monoclinic. Axes $\grave{a} : \grave{b} : \grave{c} : = 0{\cdot}9603 : 1 : 0{\cdot}9159$; $\beta = 77° 33'$.

mm''', $110 \wedge 1\bar{1}0 = 86° 19'$. *tt'*, $111 \wedge 1\bar{1}1 = 60° 50'$.
ck, $001 \wedge \bar{1}01 = 49° 32'$. *ct*, $001 \wedge 111 = 46° 58'$.

974.



Crystals usually prismatic, habit varied. Also imperfectly columnar and granular.

Cleavage: *m* rather distinct; *c*, *a* less so. Fracture small conchoidal to uneven. Sectile. H. = 2·5–3. G. = 5·9–6·1. Luster adamantine to vitreous. Color various shades of bright hyacinth-red. Streak orange-yellow. Translucent.

Comp.—Lead chromate, $PbCrO_4$ = Chromium trioxide 31·1, lead protoxide 68·9 = 100.

Pyr., etc.—In the closed tube decrepitates, blackens, but recovers its original color on cooling. B.B. fuses at 1·5, and on charcoal is reduced to metallic lead with deflagration, leaving a residue of chromium oxide, and giving a lead coating. With salt of phosphorus gives an emerald-green bead in both flames.

Obs.—First found at Berezov, in crystals in quartz veins; also at Mursinka and near Nizhni Tagilsk in the Ural; in Brazil, at Congonhas do Campo; at Rezbánya in Hungary, Moldawa in Hungary; on Luzon, one of the Philippines; from Tasmania; in the Vulture district, Maricopa Co., Arizona.

The name *Crocoite* is from *κρόκος*, *saffron.*

Phœnicochroite. Phœnicite. A basic lead chromate, $3PbO.2CrO_3$. In crystals and massive. Color between cochineal- and hyacinth-red. From Berezov in the Ural.

Vauquelinite. A phospho-chromate of lead, perhaps $2(Pb,Cu)CrO_4.(Pb,Cu)_3P_2O_8$. In crystals; also mammillary and reniform. Color green to brown. From Berezov in the Ural.

Sulphates with Chlorides, Carbonates, etc.—In part hydrous.

LEADHILLITE.

Monoclinic. Axes $\grave{a} : \grave{b} : \grave{c} = 1{\cdot}7476 : 1 : 2{\cdot}2154$; $\beta = 89° 48'$.

mm''', $110 \wedge \bar{1}10 = 120° 27'$. *cx*, $001 \wedge 111 = 68° 31'$.
cw, $001 \wedge 101 = 51° 36'$. *cm*, $001 \wedge 110 = 89° 54'$.

Twins: tw. pl. *m*, analogous to aragonite. Crystals commonly tabular ‖ *c*.

Cleavage: *c* very perfect; *a* in traces. Fracture conchoidal, scarcely observable. Rather sectile. H. = 2·5. G. = 6·26–6·44. Luster of *c* pearly, other parts resinous, somewhat adamantine. Color white, passing into yellow, green, or gray. Streak uncolored. Transparent to translucent.

Comp.—Sulphato-carbonate of lead, perhaps $4PbO.SO_3.2CO_2.H_2O$=Sulphur trioxide 7·4, carbon dioxide 8·2, lead oxide 82·7, water 1·7 = 100.

Pyr., etc.—B.B. intumesces, fuses at 1·5, and turns yellow; but becomes white on cooling. Easily reduced on charcoal. With soda affords the reaction for sulphuric acid. Effervesces briskly in nitric acid, and leaves white lead sulphate undissolved. Yields water in the closed tube.

Obs.—Found at Leadhills, with other ores of lead: Red Gill, Cumberland; at Matlock, Derbyshire. From the Mala-Calzetta lead mine near Iglesias, Sardinia (*maxite*). Observed from Arizona, at the Schulz gold mine with wulfenite, vanadinite, cerussite; partly altered to cerussite.

Susannite. Regarded at one time as rhombohedral and dimorphous with leadhillite, but probably only a modification of that species. From the Susanna mine, Leadhills, in Scotland.

Sulphohalite. $3Na_2SO_4.2NaCl$. In pale greenish yellow dodecahedrons. From Borax lake, San Bernardino Co., Cal.

Caracolite. Perhaps $Pb(OH)Cl.Na_2SO_4$. As a crystalline incrustation. Colorless. From Atacama.

Kainite. $MgSO_4.KCl + 3H_2O$. Usually granular massive and in crusts. Color white to dark flesh-red. From Stassfurt; Kalusz, Galicia.

Connellite. Probably $Cu_{15}(Cl,OH)_4SO_{16}.15H_2O$. Crystals slender, hexagonal prisms (Fig. 204, p. 69). Color fine blue. From Cornwall.

Spangolite. A highly basic sulphate of aluminium and copper, $Cu_6AlClSO_{10}.9H_2O$. In dark green hexagonal crystals (hemimorphic), tabular or short prismatic. From the neighborhood of Tombstone, Arizona.

Hanksite. $9Na_2SO_4.2Na_2CO_3.KCl$. In hexagonal prisms, short prismatic to tabular; also in quartzoids (Figs. 202, 203, p. 69). Color white to yellow. From Borax Lake, San Bernardino Co., California; also from Death Valley, Inyo Co.

B. Acid and Basic Sulphates.

Misenite. Probably acid potassium sulphate, $HKSO_4$. In silky fibers of a white color. From Cape Misene, near Naples.

BROCHANTITE.

Orthorhombic. Axes $\breve{a} : \bar{b} : \dot{c} = 0·7739 : 1 : 0·4871$.

In groups of prismatic acicular crystals ($mm''' = 75° 28'$) and drusy crusts; massive with reniform structure.

Cleavage: *b* very perfect; *m* in traces. Fracture uneven. H. = 3·5–4. G. = 3·907. Luster vitreous; a little pearly on the cleavage-face *b*. Color emerald-green, blackish green. Streak paler green. Transparent to translucent.

Comp.—A basic sulphate of copper, $CuSO_4.3Cu(OH)_2$ or $4CuO.SO_3.3H_2O$ = Sulphur trioxide 17·7, cupric oxide 70·3, water 12·0 = 100.

Pyr., etc.—Yields water, and at a higher temperature sulphuric acid, in the closed tube, and becomes black. B.B. fuses, and on charcoal affords metallic copper. With soda gives the reaction for sulphuric acid.

Obs.—Occurs in the Ural; the königine (or *königite*) was from Gumeshevsk; near Roughten Gill, in Cumberland; in Cornwall (in part *waringtonite*); at Rezbánya; in small beds at Krisuvig in Iceland (*krisuvigite*); in Mexico (*brongnartine*); Atacama. In the U. States, at Monarch mine, Chaffee Co., Colorado; in Utah, Tintic district, at the Mammoth mine.

Lanarkite. Basic lead sulphate, Pb_2SO_5. In monoclinic crystals. Color greenish white, pale yellow or gray. From Leadhills, Scotland; Siberia; the Harz.

Dolerophanite. A basic cupric sulphate, Cu_2SO_5(?). In small brown monoclinic crystals. From Vesuvius (eruption of 1868).

Caledonite. A basic sulphate of lead and copper, perhaps $2(Pb,Cu)O.SO_3.H_2O$. In small prismatic crystals. Color deep verdigris-green or bluish green. From Leadhills; Red Gill, Cumberland, etc.; Inyo Co., Cal.

Linarite. A basic sulphate of lead and copper, $(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$. In deep blue monoclinic crystals. From Leadhills; Cumberland; the Ural, etc. Also Inyo Co., California.

ANTLERITE. Perhaps $3CuSO_4.7Cu(OH)_2$. In light green soft lumps. From the Antler mine, Mohave Co., Arizona.

Alumian. Perhaps $Al_2O_3.2SO_3$. White crystalline or massive. Sierra Almagrera, Spain.

C. Normal Hydrous Sulphates.

Three well-characterized groups are included here. Two of these, the EPSOMITE GROUP and the MELANTERITE GROUP, have the same general formula, $RSO_4 + 7H_2O$, but in the first the crystallization is orthorhombic, in the second monoclinic. The species are best known from the artificial crystals of the laboratory; the native minerals are rarely crystallized. There is also the isometric ALUM GROUP, to which the same remark is applicable.

Lecontite. $(Na,NH_4,K)_2SO_4 + 2H_2O$. From bat guano in the cave of Las Piedras, near Comayagua, Central America.

MIRABILITE. Glauber Salt.

Monoclinic. Crystals like pyroxene in habit and angle. Usually in efflorescent crusts.

Cleavage: *a* perfect; *c*, *b*, in traces. H. = 1·5–2. G. = 1·481. Luster vitreous. Color white. Transparent to opaque. Taste cool, then feebly saline and bitter.

Comp.—Hydrous sodium sulphate, $Na_2SO_4 + 10H_2O$ = Sulphur trioxide 24·8, soda 19·3, water 55·9 = 100.

Pyr., etc.—In the closed tube much water; gives an intense yellow to the flame. Very soluble in water. Loses its water on exposure to dry air and falls to powder.

Obs.—Occurs at Ischl, Hallstadt, and Aussee in Upper Austria; also in Hungary, Switzerland, Italy; at the hot springs at Carlsbad, etc. Large quantities of this sodium sulphate are obtained from the waters of Great Salt Lake, Utah.

Kieserite. $MgSO_4 + H_2O$. Usually massive, granular to compact. Color white, grayish, yellowish. From Stassfurt; Hallstadt; India.

Szmikite. $MnSO_4 + H_2O$. Stalactitic. Whitish, reddish. From Felsőbánya, Hungary.

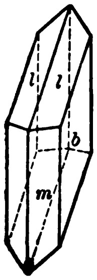
GYPSUM.

Monoclinic. Axes $\grave{a} : \bar{b} : \grave{c} = 0·6899 : 1 : 0·4124$; $\beta = 80° 42'$.

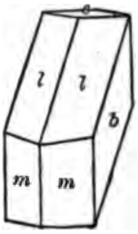
mm''', $110 \wedge 1\bar{1}0 = 68° 30'$.
cd, $001 \wedge 101 = 28° 17'$.
cl, $001 \wedge \bar{1}01 = 33° 8\frac{1}{2}'$.
ce, $001 \wedge \bar{1}03 = 11° 29'$.
vv', $011 \wedge 0\bar{1}1 = 44° 17\frac{1}{2}'$.

ll', $111 \wedge 1\bar{1}1 = 36° 12'$.
nn', $\bar{1}11 \wedge \bar{1}\bar{1}1 = 41° 20'$.
ml, $110 \wedge 111 = 49° 9'$.
mn, $110 \wedge \bar{1}1\bar{1} = 59° 15'$.

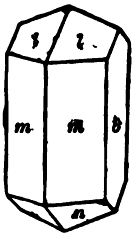
975.



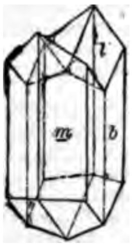
976.



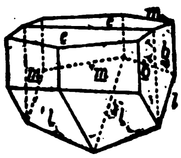
977.



978.



979.



Crystals usually simple in habit, common form flattened ‖ *b* or prismatic to acicular ‖ $\grave{c}$; again prismatic by extension of *l* (111). Also lenticular by rounding of *l* (111) and *e* ($\bar{1}03$). The form *e* ($\bar{1}03$), whose faces are usually rough and convex, is nearly at right angles to the vertical axis (edge m/m'''), hence the apparent hemimorphic character of the twin (Fig. 979). Simple crystals often with warped as well as curved surfaces. Also foliated massive; lamellar-stellate; often granular massive; and sometimes nearly impalpable. Twins: tw. pl. *a*, very common, often the familiar swallow-tail twins.

Cleavage: *b* eminent, yielding easily thin polished folia; *a* (100), giving a surface with conchoidal fracture; *n* ($\bar{1}11$), with a fibrous fracture ‖ *t* ($\bar{1}01$); a cleavage fragment has the rhombic form of Fig. 549, p. 222, with plane angles of 66° and 114°. H.= 1·5–2. G.= 2·314–2·328, when in pure crystals. Luster of *b* pearly and shining, other faces subvitreous. Massive varieties often glistening, sometimes dull earthy. Color usually white; sometimes gray, flesh-red, honey-yellow, ocher-yellow, blue; impure varieties often black, brown, red, or reddish brown. Streak white. Transparent to opaque.

Optically +. Ax. pl. $\parallel b$, and $\mathrm{Bx} \wedge \dot{c} = +52\frac{1}{2}°$ (at 9·4° C.), (cf. Figs. 549, 550, p. 222). Dispersion $\rho \wedge v$; also inclined strong. $\mathrm{Bx_r} \wedge \mathrm{Bx_{bl}} = 0° 30'$. $2\mathrm{E_r} = 95° 14'$ at 20°. $\beta_y = 1·5226$, $\gamma - \alpha = 0·009$. On the effect of heat on the optical properties, see p. 225.

Var.—1. *Crystallized*, or *Selenite;* colorless, transparent; in distinct crystals, or broad folia, often large. Usually flexible and yielding a fibrous fracture ‖ *t* ($\bar{1}01$), but the variety from Montmartre rather brittle.

2. *Fibrous;* coarse or fine. Called *Satin spar*, when fine-fibrous, with pearly opalescence.

3. *Massive; Alabaster*, a fine-grained variety, white or delicately shaded; *earthy* or *rock-gypsum*, a dull-colored rock, often impure with clay, calcium carbonate or silica.

Also, in caves, curious curved forms, often grouped in rosettes and other shapes.

Comp.—Hydrous calcium sulphate, $\mathrm{CaSO_4} + 2\mathrm{H_2O}$ = Sulphur trioxide 46·6, lime 32·5, water 20·9 = 100.

Pyr., etc.—In the closed tube gives off water and becomes opaque. Fuses at 2·5–3, coloring the flame reddish yellow. For other reactions see ANHYDRITE, p. 528. Ignited at a temperature not exceeding 260° C., it again combines with water when moistened, and becomes firmly solid. Soluble in hydrochloric acid, and also in 400 to 500 parts of water.

Diff.—Characterized by its softness in all varieties, and by cleavages in crystallized kinds; it does not effervesce with acids like calcite, nor gelatinize like the zeolites; harder than talc and yields much water in the tube.

Obs.—Gypsum often forms extensive beds in connection with various stratified rocks, especially limestones, and marlites or clay beds. It occurs occasionally in crystalline rocks. It is also a product of volcanoes, occurring about fumaroles, or where sulphur gases are escaping, being formed from the sulphuric acid generated, and the lime afforded by the decomposing lavas. It is also produced by the decomposition of pyrite when lime is present. Gypsum is also deposited on the evaporation of sea-water and brines, in which it exists in solution.

Fine specimens are found in the salt mines of Bex in Switzerland; Hall in Tyrol; the sulphur mines of Sicily; in the clay of Shotover Hill, near Oxford; and large lenticular crystals at Montmartre, near Paris. A noted locality of alabaster occurs at Castelino, 35 m. from Leghorn, whence it is taken to Florence for the manufacture of vases, figures, etc.

Occurs in extensive beds in several of the United States, and more particularly N. York, Ohio, Illinois, Virginia, Tennessee, and Arkansas, and is usually associated with salt springs, also with rock salt. Also on a large scale in Nova Scotia, etc.

Handsome selenite and snowy gypsum occur in *N. York*, near Lockport in limestone. In *Maryland*, large grouped crystals on the St. Mary's in clay. In *Ohio*, large transparent crystals have been found at Ellsworth and Canfield, Trumbull Co. In *Tenn.*, selenite and alabaster in Davidson Co. In *Kentucky*, in Mammoth Cave, it has the forms of rosettes, or flowers, vines, and shrubbery. Also common in isolated crystals and masses, in the Cretaceous clays in the western U. S. In enormous crystals, several feet in length, in Wayne Co., Utah. In *N. Scotia*, in Sussex, Kings Co., large single and grouped crystals, which mostly contain much symmetrically disseminated sand.

Named from γύψος, the Greek for the mineral, but more especially for the *calcined* mineral. The derivation ordinarily suggested, from γῆ, *earth*, and ἕψέιν, *to cook*, corresponds with this, the most common use of the word among the Greeks.

Burnt gypsum is called *Plaster-of-Paris*, because the Montmartre gypsum quarries, near Paris, are, and have long been, famous for affording it.

Ilesite. $(Mn,Zn,Fe)SO_4 + 4H_2O$. In loosely adherent aggregates. Color clear green. From Colorado.

Epsomite Group. $RSO_4 + 7H_2O$. Orthorhombic.

Epsomite	$MgSO_4 + 7H_2O$	$\breve{a} : \bar{b} : \dot{c} = 0·9902 : 1 : 0·5709$
	$(Fe,Mg)SO_4 + 7H_2O$	
Goslarite	$ZnSO_4 + 7H_2O$	0·9807 : 1 : 0·5631
Ferro-goslarite	$(Zn,Fe)SO_4 + 7H_2O$	
Morenosite	$NiSO_4 + 7H_2O$	0·9816 : 1 : 0·5655

EPSOMITE. Epsom Salt.

Orthorhombic. Usually in botryoidal masses and delicately fibrous crusts. Cleavage: *b* very perfect. Fracture conchoidal. H. = 2·0–2·5. G. = 1·751. Luster vitreous to earthy. Streak and color white. Transparent to translucent. Taste bitter and saline.

Comp.—Hydrous magnesium sulphate, $MgSO_4 + 7H_2O$ = Sulphur trioxide 32·5, magnesia 16·3, water 51·2 = 100.

Obs.—Common in mineral waters, and as a delicate fibrous or capillary efflorescence on rocks, in the galleries of mines, and elsewhere. In the former state it exists at Epsom, England, and at Sedlitz and Saidschitz (or Saidschütz) in Bohemia. At Idria in Carniola it occurs in silky fibers, and is hence called *hairsalt* by the workmen. Also obtained at the gypsum quarries of Montmartre, near Paris. Also found at Vesuvius, at the eruptions of 1850 and 1855.

The floors of the limestone caves of Kentucky, Tennessee, and Indiana, are in many instances covered with epsomite, in minute crystals, mingled with the earth. In the Mammoth Cave, Ky., it adheres to the roof in loose masses like snowballs.

Goslarite. $ZnSO_4 + 7H_2O$. Commonly massive. Color white, reddish, yellowish. Formed by the decomposition of sphalerite, and found in the passages of mines, as at the Rammelsberg mine near Goslar, in the Harz, etc. In Montana at the Gagnon mine, Butte. *Ferro-goslarite* (4·9 p. c. $FeSO_4$) occurs with sphalerite at Webb City, Jasper Co., Missouri.

Morenosite. $NiSO_4 + 7H_2O$. In acicular crystals; also fibrous, as an efflorescence. Color apple-green to greenish white. A result of the alteration of nickel ores, as near Cape Hortegal, in Galicia; Riechelsdorf, in Hesse, etc.

Melanterite Group. $RSO_4 + 7H_2O$. Monoclinic.

Melanterite	$FeSO_4 + 7H_2O$	$\grave{a}$: ƀ : $\dot{c}$ = 1·1828 : 1 : 1·5427	β = 75° 44′
Luckite	$(Fe,Mn)SO_4 + 7H_2O$		
Mallardite	$MnSO_4 + 7H_2O$		
Pisanite	$(Fe,Cu)SO_4 + 7H_2O$	1·1609 : 1 : 1 5110	74° 38′
Bieberite	$CoSO_4 + 7H_2O$	1·1815 : 1 : 1·5325	75° 20′
Cupromagnesite	$(Cu,Mg)SO_4 + 7H_2O$		

Chalcanthite $CuSO_4 + 5H_2O$ Triclinic

$\breve{a} : \bar{b} : \dot{c} = 0·5656 : 1 : 0·5507; \alpha = 82° 21', \beta = 73° 11', \gamma = 77° 37'$

The species here included are the ordinary vitriols. They are identical in general formula with the species of the Epsomite group, and are regarded as the same compound essentially under oblique crystallization. The copper sulphate diverges from the others in crystallization, and contains but 5 of water.

MELANTERITE. Copperas.

Monoclinic. Usually capillary, fibrous, stalactitic, and concretionary; also massive, pulverulent. Cleavage: *c* perfect; *m* less so. Fracture conchoidal. Brittle. H. = 2. G. = 1·89–1·90. Luster vitreous. Color, various shades of green, passing into white; becoming yellowish on exposure. Streak uncolored. Subtransparent to translucent. Taste sweetish, astringent, and metallic.

Comp.—Hydrous ferrous sulphate, $FeSO_4 + 7H_2O$ = Sulphur trioxide 28·8, iron protoxide 25·9, water 45·3 = 100. Manganese and magnesium sometimes replace part of the iron.

Obs.—Proceeds from the decomposition of pyrite or marcasite; thus near Goslar in the Harz; Bodenmais in Bavaria; Falun, Sweden, and elsewhere. Usually accompanies pyrite in the U. States, as an efflorescence. *Luckite* (1·9 p. c. MnO) is from the "Lucky Boy" mine, Butterfield Cañon, Utah.

Mallardite. $MnSO_4 + 7H_2O$. Fibrous, massive; colorless. From the mine "Lucky Boy," south of Salt Lake, Utah.

Pisanite. $(Fe,Cu)SO_4 + 7H_2O$. CuO 10 to 15 p. c. In concretionary and stalactitic forms. Color blue. From Turkey.

SALVADORITE. A copper-iron vitriol near pisanite. From the Salvador mine Quetena, Chili.

Bieberite. $CoSO_4 + 7H_2O$. Usually in stalactites and crusts. Color flesh- and rose-red. From Bieber, in Hesse, etc. *Cupromagnesite* is from Vesuvius.

CHALCANTHITE. Blue Vitriol. Kupfervitriol *Germ.*

Triclinic. Crystals commonly flattened ‖ *p* (111) (Figs. 339–341, p. 109). Occurs also massive, stalactitic, reniform, sometimes with fibrous structure.

Cleavage: *M*, *m*, *p* imperfect. Fracture conchoidal. Brittle. H. = 2·5. G. = 2·12–2·30. Luster vitreous. Color Berlin-blue to sky-blue, of different shades; sometimes a little greenish. Streak uncolored. Subtransparent to translucent. Taste metallic and nauseous.

Comp.—Hydrous cupric sulphate, $CuSO_4 + 5H_2O$ = Sulphur trioxide 32·1, cupric oxide 31·8, water 36·1 = 100.

Pyr., etc.—In the closed tube yields water, and at a higher temperature sulphur trioxide. B.B. with soda on charcoal yields metallic copper. With the fluxes reacts for copper. Soluble in water; a drop of the solution placed on a surface of iron coats it with metallic copper.

Obs.—Found in waters issuing from mines and in connection with rocks containing chalcopyrite, by the alteration of which it is formed; thus at the Rammelsberg mine near Goslar in the Harz; Falun in Sweden; Parys mine, Anglesea; at various mines in Co. of Wicklow; Rio Tinto mine, Spain. From the Hiwassee copper mine, also in large quantities at other mines, in Polk Co., Tennessee. In Arizona, near Clifton, Graham Co., and Jerome, Yavapai Co.

Syngenite. Kaluszite. $CaSO_4.K_2SO_4 + H_2O$. In prismatic (monoclinic) crystals. Colorless or milky-white. From Kalusz, Galicia.

Löweite. $MgSO_4.Na_2SO_4 + 2\frac{1}{2}H_2O$. Massive, cleavable. Color pale yellow. From Ischl, Austria.

Blödite. $MgSO_4.Na_2SO_4 + 4H_2O$. Crystals short prismatic, monoclinic; also massive granular or compact. Colorless to greenish, yellowish, red. From the salt mines of Ischl; at Hallstadt (*simonyite*); at Stassfurt; the salt lakes of Astrakhan (*astrakanite*). Asia; India; Chili, etc.

Leonite. $MgSO_4.K_2SO_4 + 4H_2O$. In monoclinic crystals from Westeregeln and Leopoldshall, Germany.

Boussingaultite. $(NH_4)_2SO_4.MgSO_4 + 6H_2O$. From the boric acid lagoons, Tuscany.

Picromerite. $MgSO_4.K_2SO_4 + 6H_2O$. As a white crystalline incrustation. From Vesuvius with *cyanochroite*, an isomorphous species in which copper replaces the magnesium. Also at Stassfurt (*schoenite*); at Aschersleben; Galusz in East Galicia.

Polyhalite. $2CaSO_4.MgSO_4.K_2SO_4 + 2H_2O$. Usually in compact fibrous or lamellar masses. Color flesh- or brick-red. Occurs at the mines of Ischl, Hallstadt, etc., in Austria; Berchtesgaden, Bavaria; Stassfurt.

Alum Group. Isometric.

$$\overset{\text{I}}{R}Al(SO_4)_2 + 12H_2O \text{ or } \overset{\text{I}}{R}_2SO_4.Al_2(SO_4)_3 + 24H_2O.$$

Kalinite	Potash Alum	$KAl(SO_4)_2 + 12H_2O$
Tschermigite	Ammonia Alum	$(NH_4)Al(SO_4)_2 + 12H_2O$
Mendozite	Soda Alum	$NaAl(SO_4)_2 + 12H_2O$

The ALUMS proper are isometric in crystallization and, chemically, are hydrous sulphates of aluminium with an alkali metal and 12 (*i.e.*, if the formula is doubled, 24) molecules of water. The species here included occur very sparingly in nature, and are best known in artificial form in the laboratory.

The HALOTRICHITES are oblique in crystallization, very commonly fibrous in structure, and are hydrous sulphates of aluminium with magnesium, manganese, etc.; the amount of water in some cases is given as 22 molecules, and in others 24, but it is not always easy to decide between the two. Here belong:

Pickeringite. Magnesia Alum. $MgSO_4.Al_2(SO_4)_3 + 22H_2O$. In long fibrous masses; and in efflorescences.

Halotrichite. Iron Alum. $FeSO_4.Al_2(SO_4)_3 + 24H_2O$. In yellowish silky fibrous forms.

Apjohnite. Manganese Alum. $MnSO_4.Al_2(SO_4)_3 + 24H_2O$. Bushmanite contains MgO. In fibrous or asbestiform masses; also as crusts and efflorescences.

Dietrichite. $(Zn,Fe,Mn)SO_4.Al_2(SO_4)_3 + 22H_2O$.

MASRITE. A fibrous alum from Egypt supposed to contain a new element, masrium.

Coquimbite. $Fe_2(SO_4)_3 + 9H_2O$. Rhombohedral. Granular massive. Color white, yellowish, brownish. From the Tierra Amarilla near Copiapo, Chili (not from Coquimbo.)

Quenstedtite. $Fe_2(SO_4)_3 + 10H_2O$. In reddish tabular crystals. With coquimbite Chili.

Ihleite. $Fe_2(SO_4)_3 + 12H_2O$? An orange-yellow efflorescence on graphite. From Mugrau, Bohemia.

Alunogen. $Al_2(SO_4)_3 + 18H_2O$. Usually in delicate fibrous masses or crusts; massive. Color white, or tinged with yellow or red. From near Bilin, Bohemia; Bodenmais; Pusterthal, Tyrol.

Kröhnkite. $CuSO_4.Na_2SO_4 + 2H_2O$. Massive, coarsely fibrous. Color azure-blue. From Calama, Atacama.

PHILLIPITE. Perhaps $CuSO_4.Fe_2(SO_4)_3 + xH_2O$. In blue fibrous masses, Chili. Found at the copper mines in the Cordilleras of Condes, province of Santiago, Chili.

Ferronatrite. $3Na_2SO_4.Fe_2(SO_4)_3 + 6H_2O$. Rarely in acicular crystals; usually in spherical forms. Color greenish or gray to white. From Sierra Gorda near Caracoles, Chili.

Römerite. Perhaps $FeSO_4.Fe_2(SO_4)_3 + 12H_2O$. In tabular crystals; granular, massive. Color chesnut-brown. From Goslar in the Harz; Persia, Chili.

Basic Hydrous Sulphates.

Langite. Near brochantite. $CuSO_4.3Cu(OH)_2 + H_2O$. Usually in fibro-lamellar, concretionary crusts. Color blue to greenish blue. From Cornwall.

Herrengrundite. $2(CuOH)_2SO_4.Cu(OH)_2 + 3H_2O$ with one-fifth of the copper replaced by calcium. In thin tabular crystals; usually in spherical groups. Color emerald-green, bluish green. From Herrengrund, Hungary.

Kamarezite. A hydrous basic copper sulphate from Laurion, Greece.

Cyanotrichite. Lettsomite. Perhaps $4CuO.Al_2O_3.SO_3.8H_2O$. In velvet-like druses; in spherical forms. Color bright blue. From Moldawa in the Banat; Cap Garonne, France. In Utah and Arizona.

Serpierite. A basic sulphate of copper and zinc. In minute crystals, tabular, in tufts. Color bluish green. From Laurion, Greece.

COPIAPITE.

Monoclinic. Usually in loose aggregations of crystalline scales, or granular massive; incrusting.

Cleavage: *b* (010). H. = 2·5. G. = 2·103. Luster pearly. Color sulphur-yellow, citron-yellow. Translucent.

Comp.—A basic ferric sulphate, perhaps $2Fe_2O_3.5SO_3.18H_2O$ = Sulphur trioxide 38·3, iron sesquioxide 30·6, water 31·1 = 100.

Misy is an old term, which has been somewhat vaguely applied. It seems to belong in part here and in part also to other related species.

Pyr., etc.—Yields water, and at a higher temperature sulphuric acid. On charcoal becomes magnetic, and with soda affords the reaction for sulphuric acid. With the fluxes reacts for iron. Soluble in water, and decomposed by boiling water.

Obs.—The original copiapite was from Copiapo, Chili.

Other hydrated ferric sulphates:

Castanite. $Fe_2O_3.2SO_3.8H_2O$. Color chestnut-brown. From Sierra Gorda, Chili.

Utahite. $3Fe_2O_3.2SO_3.7H_2O$. In aggregates of fine scales. Color orange-yellow From the Tintic distr., Utah.

Amarantite. $Fe_2O_3.2SO_3.7H_2O$. Usually in columnar or bladed masses, also radiated. Color amaranth-red. From near Caracoles, Chili. *Hohmannite* is the same partially altered; this is probably also true of *paposite*.

Fibroferrite. $Fe_2O_3.2SO_3.10H_2O$. In delicately fibrous aggregates. Color pale yellow, nearly white. From the Tierra Amarilla near Copiapo, Chili.

Raimondite. $2Fe_2O_3.3SO_3\ 7H_2O$. In thin six-sided tables. Color between honey- and ocher-yellow. From the tin mines of Ehrenfriedersdorf; mines of Bolivia.

Carphosiderite. $3Fe_2O_3.4SO_3.10H_2O$. In reniform masses, and incrustations; also in micaceous lamellæ. Color straw-yellow. From Greenland.

Glockerite. $2Fe_2O_3.SO_3.6H_2O$. Massive, sparry or earthy; stalactitic. Color brown to ocher-yellow to pitch-black; dull green. From Goslar and Modum.

Knoxvillite. A hydrous basic sulphate of chromium, ferric iron, and aluminium. In rhombic plates. Color greenish yellow. From the Redington mercury mine, Knoxville, California.

REDINGTONITE. A hydrous chromium sulphate, in finely fibrous masses of a pale purple color. Same locality as knoxvillite.

Cyprusite. Perhaps $7Fe_2O_3.Al_2O_3.10SO_3.14H_2O$. An aggregation of microscopic crystals. Color yellowish. From the island of Cyprus.

Aluminite (Websterite). $Al_2O_3.SO_3.9H_2O$. Usually in white earthy reniform masses, compact. From near Halle, in clay; also at Newhaven, Sussex, and elsewhere.

Paraluminite. Near aluminite, but supposed to be $2Al_2O_3.SO_3.15H_2O$.

Felsöbanyite. $2Al_2O_3.SO_3.10H_2O$. Massive; in scaly concretions. Color snow-white. From near Felsöbánya, Hungary.

Botryogen. Perhaps $MgO.FeO.Fe_2O_3\ 4SO_3.18H_2O$. Usually in reniform and botryoidal shapes. Color deep hyacinth-red, ocher-yellow. From Falun, Sweden; also from Persia.

Sideronatrite. $2Na_2O.Fe_2O_3\ 4SO_3.7H_2O$. Fibrous, massive. Color yellow. From the province of Tarapacá, Chili. Also on the Urus plateau, near Sarakaya, on the island, Cheleken, in the Caspian Sea (*urusite*).

Voltaite. Perhaps $5(K_2,Fe)O.2(Al,Fe)_2O_3.10SO_3.15H_2O$. In octahedrons, etc. Color dull oil-green to brown or black. From the solfatara near Naples; also Persia.

Metavoltine. Perhaps $5(K_2,Na_2,Fe)O.3Fe_2O_3.12SO_3.18H_2O$. In aggregates of minute yellow scales. Occurs with voltaite in Persia.

ALUNITE. Alumstone. Alaunstein.

Rhombohedral. Axis $\dot{c} = 1\cdot2520$. In rhombohedrons, resembling cubes ($rr' = 90°\ 50'$). Also massive, having a fibrous, granular, or impalpable texture.

Cleavage: *c* distinct; *r* in traces. Fracture flat conchoidal, uneven; of massive varieties splintery; and sometimes earthy. Brittle. H. = 3·5–4. G. = 2·58–2·752. Luster of *r* vitreous, basal plane somewhat pearly. Color white, sometimes grayish or reddish. Streak white. Transparent to subtranslucent. Optically positive.

Comp.—Hydrous sulphate of aluminium and potassium, $K_2O.3Al_2O_3.4SO_3.6H_2O$ = Sulphur trioxide 38·6, alumina 37·0, potash 11·4, water 13·0 = 100. The formula may be written $K(AlO)_3(SO_4)_2 + 3H_2$.

Pyr., **etc.**—B.B. decrepitates, and is infusible. In the closed tube yields water, sometimes also ammonium sulphate, and at a higher temperature sulphurous and sulphuric oxides. Heated with cobalt solution affords a fine blue color. With soda and charcoal infusible, but yields a hepatic mass. Soluble in sulphuric acid.

Obs.—Forms seams in trachytic and allied rocks, where it has been formed as a result of the alteration of the rock by means of sulphurous vapors; as at Tolfa, near Civita Vecchia; in Hungary; on Milo, Grecian Archipelago; at Mt. Dore, France. In the U. S., associated with diaspore, in rhombohedral crystals, tabular through the presence of *c* (0001) at the Rosita Hills, Custer Co., Colorado.

JAROSITE. Gelbeisenerz.

Rhombohedral. Axis $\dot{c} = 1\cdot2492$; $rr' = 90°\ 45'$, $cr = 55°\ 16'$. Often in druses of minute crystals; also fibrous, granular massive; in nodules, or as an incrustation.

Cleavage: *c* distinct. Fracture uneven. Brittle. H. = 2·5–3·5. G. = 3·15–3·26 cryst. Luster vitreous to subadamantine; brilliant, also dull. Color ocher-yellow, yellowish brown, clove-brown. Streak yellow, shining.

Comp.—$K_2O.3Fe_2O_3.4SO_3.6H_2O$ = Sulphur trioxide 31·9, iron sesquioxide 47·9, potash 9·4, water 10·8 = 100. The formula may be written $K(FeO)_3(SO_4)_2 + 3H_2O$.

Obs.—The original Gelbeisenerz was from Luschitz, between Kolosoruk and Bilin, Bohemia, in brown coal; and later from Modum, Norway, in alum slate. The jarosite was from Barranco Jaroso, in the Sierra Almagrera, Spain; also from other points. In the U. S., on quartz in the Vulture mine, Arizona; in Chaffee County, Col.; Tintic district, Utah.

Löwigite. Perhaps $K_2O.3Al_2O_3.4SO_3.9H_2O$. In rounded masses, similar to compact alunite. Found in a coal bed at Tabrze in Upper Silesia; also with alunite at Tolfa.

Ettringite. Perhaps $6CaO.Al_2O_3.3SO_3.33H_2O$. In minute colorless acicular crystals. From limestone-inclusions in lava, near Mayen, Rhenish Prussia.

Quetenite. $MgO.Fe_2O_3.3SO_3.13H_2O$. Massive, in indistinct crystals. Color reddish brown. From Quetena, Chili.

Zincaluminite. $2ZnSO_4.4Zn(OH)_2.6Al(OH)_3 + 5H_2O$. In minute hexagonal plates. Color white, bluish. From Laurion, Greece.

Johannite. A hydrous sulphate of uranium and copper. In druses or reniform masses of a green color. From Joachimsthal.

Uranopilite. Perhaps $CaU_8S_2O_{31}.25H_2O$. In velvety incrustations; yellow. From Johanngeorgenstadt.

Zippeite, *voglianite*, *uraconite* are uncertain uranium sulphates, also from Joachimsthal.

Tellurates; also Tellurites, Selenites.

Montanite. $Bi_2O_3.TeO_3.2H_2O$. In earthy incrustations; yellowish to white. From Highland, Montana, with tetradymite.

Emmonsite. Probably a hydrated ferric tellurite. In thin yellow-green scales. From near Tombstone, Arizona.

Durdenite. Hydrous ferric tellurite, $Fe_2(TeO_3)_3 + 4H_2O$. In small mammillary forms; greenish yellow. Honduras.

Chalcomenite. Hydrous cupric selenite, $CuSeO_3 + 2H_2O$. In small blue monoclinic crystals. From the Cerro de Cacheuta, Argentina, with silver, copper selenides.

MOLYBDOMENITE is lead selenite and **COBALTOMENITE** probably cobalt selenite, from the same locality as chalcomenite.

Oxygen Salts.

7. TUNGSTATES, MOLYBDATES.

The monoclinic Wolframite Group and the tetragonal Scheelite Group are included here.

Wolframite Group.

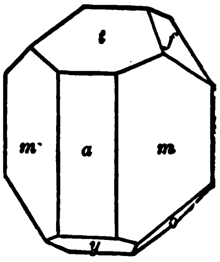
Wolframite	$(Fe,Mn)WO_4$	$\grave{a} : \bar{b} : \acute{c} = 0{\cdot}8300 : 1 : 0{\cdot}8678$	$\beta = 89^\circ\ 22'$
Hübnerite	$MnWO_4$	$0{\cdot}8362 : 1 : 0{\cdot}8668$	$89^\circ\ 7\frac{1}{2}'$

WOLFRAMITE. Wolfram.

Monoclinic. Axes: $\grave{a} : \bar{b} : \acute{c} = 0{\cdot}8300 : 1 : 0{\cdot}8678$; $\beta = 89^\circ\ 22'$.

mm''', 110 ∧ 1$\bar{1}$0 = 79° 23'. *ay'*, 100 ∧ 10$\bar{2}$ = 62° 54'.
at, 100 ∧ 102 = 61° 54'. *ff'*, 011 ∧ 0$\bar{1}$1 = 81° 54'.

980.



Twins: (1) tw. axis $\acute{c}$ with *a* as comp.-face; (2) tw. pl. *k* (023), Fig. 419, p. 130. Crystals commonly tabular ∥ *a*; also prismatic. Faces in prismatic zone vertically striated. Often bladed, lamellar, coarse divergent columnar, granular.

Cleavage: *b* very perfect; also parting ∥ *a*, and ∥ *t* (102). Fracture uneven. Brittle. H. = 5–5·5. G. = 7·2–7·5. Luster submetallic. Color dark grayish or brownish black. Streak nearly black. Opaque. Sometimes weakly magnetic.

Comp., Var.—Tungstate of iron and manganese $(Fe,Mn)WO_4$. Fe : Mn = chiefly 4 : 1 (FeO 18·9, MnO 4·7 p. c.) and 2 : 3 (FeO 9·5, MnO 14·0).

Pyr., etc.—Fuses B.B. easily (F. = 2·5–3) to a globule, which has a crystalline surface and is magnetic. With salt of phosphorus gives a clear reddish yellow glass while hot, which is paler on cooling; in R.F. becomes dark red; on charcoal with tin, if not too saturated, the bead assumes on cooling a green color, which continued treatment in R.F. changes to reddish yellow. With soda and niter on platinum foil fuses to a bluish green manganate. Decomposed by aqua regia with separation of tungstic acid as a yellow powder. Sufficiently decomposed by concentrated sulphuric acid, or even hydrochloric acid, to give a colorless solution, which, treated with metallic zinc, becomes intensely blue, but soon bleaches on dilution.

Obs.—Wolframite is often associated with tin ores; also in quartz, with native bismuth, scheelite, pyrite, galena, sphalerite, etc. In fine crystals at Schlackenwald, Zinnwald; Schneeberg, Freiberg, Altenberg; at Nerchinsk, Siberia; Chanteloup, near Limoges, France; near Redruth and elsewhere in Cornwall with tin ores. In S. America, at Oruro in Bolivia With tin stone at various points in New South Wales.

In the U. States at Lane's mine, Monroe, Conn.; Flowe mine, Mecklenburg Co., N. C., with scheelite; in Missouri, near Mine la Motte.

Hübnerite. Near wolframite, but containing 20 to 25 p. c. MnO. Usually in bladed forms, rarely in distinct terminated crystals. Color brownish red to hair-brown to nearly

black. Streak yellowish brown, greenish gray. Often translucent. Mammoth dist., Nevada; Ouray County, Col.; near Silverton, San Juan Co.; Black Hills, S. Dakota, etc. Also in Peru, and in rhodochrosite at Adervielle in the Pyrenees.

Scheelite Group. Tetragonal-pyramidal.

Scheelite	$CaWO_4$	pp' (111 ∧ $1\bar{1}1$) = 79° 55½′	$\dot{c}$ = 1·5360
Cuprotungstite	$CuWO_4$		
Cuproscheelite	$(Ca,Cu)WO_4$		
Powellite	$Ca(Mo,W)O_4$	80° 1′	$\dot{c}$ = 1·5445
Stolzite	$PbWO_4$	80° 15′	$\dot{c}$ = 1·5667
Wulfenite	$PbMoO_4$	80° 22′	$\dot{c}$ = 1·5771

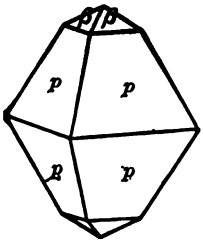
The SCHEELITE GROUP includes the tungstates and molybdates of calcium and lead; also copper. In crystallization they belong to the Pyramidal Group of the Tetragonal System. Wulfenite is probably hemimorphic.

SCHEELITE.

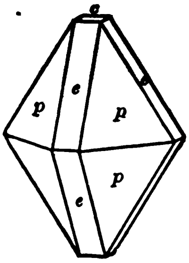
Tetragonal-pyramidal. Axis $\dot{c}$ = 1·5356.

ee′, 101 ∧ 011 = 72° 40½′. *pp′*, 111 ∧ $\bar{1}11$ = 79° 55½′.
ce, 001 ∧ 101 = 56° 56′. *cp*, 001 ∧ $\bar{1}\bar{1}1$ = 65° 16½′.

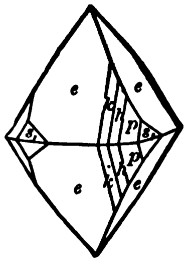
981.



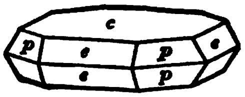
982.



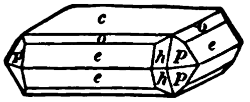
983.



984.



985.



Forms: *o* (102), *e* (101), *β* (113), *p* (111), *k* (515), *h* (313), *s*, (131).

Twins: (1) tw. pl. *a*, both contact- and penetration-twins (Fig. 378, p. 125). Habit octahedral, also tabular. Symmetry shown by faces *k, h, s* (Fig. 983). Also reniform with columnar structure; massive granular.

Cleavage: *p* (111) most distinct; *e* (101) interrupted. Fracture uneven. Brittle. H. = 4·5–5. G. = 5·9–6·1. Luster vitreous, inclining to adamantine. Color white, yellowish white, pale yellow, brownish, greenish, reddish. Streak white. Transparent to translucent. Optically +. Indices: ω_r = 1·918. ϵ_r = 1·934.

Comp.—Calcium tungstate, $CaWO_4$ = Tungsten trioxide 80·6, lime 19·4 = 100.

Molybdenum is usually present (to 8 p. c.). Copper may replace calcium, see cuproscheelite.

Pyr., etc.—B.B. in the forceps fuses at 5 to a semi-transparent glass. Soluble with borax to a transparent glass, which afterward becomes opaque and crystalline. With salt of phosphorus forms a glass, colorless in outer flame, in inner green when hot, and fine blue when cold; varieties containing iron require to be treated on charcoal with tin before the blue color appears. In hydrochloric or nitric acid decomposed, leaving a yellow powder soluble in ammonia.

Obs.—Scheelite is usually associated with crystalline rocks, and is commonly found in connection with cassiterite, topaz, fluorite, apatite, molybdenite, or wolframite, in quartz; also associated with gold. Thus at Schlackenwald and Zinnwald, Bohemia; Altenberg, Saxony; Riesengrund in the Riesengebirge; the Knappenwand in the Untersulzbachthal, Tyrol; Carrock Fells in Cumberland; Traversella in Piedmont; Meymac, Corrèze, France (containing Ta_2O_5); Sweden; Pitkäranta in Finland. In New South Wales, at Adelong, from a gold mine; New Zealand, massive; Mt. Ramsay, Tasmania, with cassiterite.

In the U. States, at Lane's Mine, Monroe, and at Trumbull; Flowe mine, Mecklenburg Co., N. Carolina; the Mammoth mining district, Nevada; with gold at the Charity mine, Warren's, Idaho; Lake Co., Colorado. In quartz veins in Risborough and Marlow, Beauce county, Quebec.

Cuprotungstite. Cupric tungstate, $CuWO_4$. From the copper mines of Llamuco, near Santiago, Chili. CUPROSCHEELITE, from the vicinity of La Paz, Lower California, is $(Ca,Cu)WO_4$, with 6·8 p. c. CuO; color green.

Powellite. Calcium molybdate with calcium tungstate (10 p. c. WO_3), $Ca(Mo,W)O_4$. In minute yellow tetragonal pyramids. G. = 4·849. From western Idaho; Houghton Co., Mich.

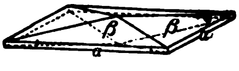
Stolzite. Lead tungstate, $PbWO_4$. In pyramidal tetragonal crystals. H. = 2·75–3. G. = 7·87–8·13. Color green to gray or brown. Zinnwald.

Raspite. Has the same composition as stolzite, but is referred to the monoclinic system. In small tabular crystals. Color brownish yellow. From the Broken Hill mines, New South Wales.

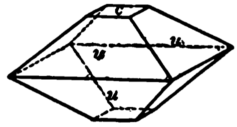
WULFENITE. Gelbbleierz, Molybdänbleispath, *Germ.*

Tetragonal-pyramidal; hemimorphic. Axis $\dot{c}$ = 1·5771.

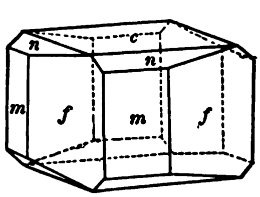
986.



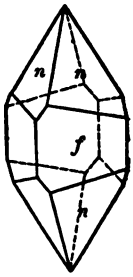
987.



988.



989.



cu, 001 ∧ 102 = 38° 15′.	*uu′*, 102 ∧ 012 = 51° 56′.
ce, 001 ∧ 101 = 57° 37′.	*ee′*, 101 ∧ 011 = 73° 20′.
cn, 001 ∧ 111 = 65° 51′.	*nn′*, 111 ∧ $\bar{1}$11 = 80° 22′.

Crystals commonly square tabular, sometimes extremely thin; less frequently octahedral; also prismatic. Hemimorphism sometimes distinct. Also granularly massive, coarse or fine, firmly cohesive.

Cleavage: *n* (111) very smooth; *c*, *s* (113) less distinct. Fracture subconchoidal. Brittle. H. = 2·75–3. G. = 6·7–7·0. Luster resinous or adamantine. Color wax- to orange-yellow, siskin- and olive-green, yellowish gray, grayish white to nearly colorless, brown; also orange to bright red. Streak white. Subtransparent to subtranslucent. Optically negative. Indices: $\omega_r = 2{\cdot}402$, $\epsilon_r = 2{\cdot}304$.

Comp.—Lead molybdate, $PbMoO_4$ = Molybdenum trioxide 39·3, lead oxide 60·7 = 100. Calcium sometimes replaces the lead.

Pyr., etc.—B.B. decrepitates and fuses below 2. With salt of phosphorus in O.F. gives a yellowish-green glass, which in R.F. becomes dark green. With soda on charcoal yields metallic lead. Decomposed on evaporation with hydrochloric acid, with the formation of lead chloride and molybdic oxide; on moistening the residue with water and adding metallic zinc, it gives an intense blue color, which does not fade on dilution of the liquid.

Obs.—Occurs in veins with other ores of lead. At Bleiberg, Carinthia; Rezbánya, Hungary; Přibram; Moldawa in the Banat; Annaberg, Schneeberg, etc.

In the U. States, sparingly at the Southampton lead mine, Mass., and near Sing Sing, N. Y.; near Phenixville, Pa.; at the Comstock lode in Nevada; in large thin orange-yellow tables at the Tecomah mine, Utah. In New Mexico, pale yellow crystals in the Organ Mts. In Arizona, large deep red crystals at the Hamburg and other mines, Yuma Co., often with red vanadinite; also at the Castle Dome district, 80 miles distant; at the Mammoth gold mine near Oracle, Pinal Co., with vanadinite and descloizite.

Named after the Austrian mineralogist Wülfen (1728–1805).

Reinite. Ferrous tungstate, $FeWO_4$. In blackish-brown tetragonal pyramids, perhaps pseudomorphous. H. = 4. G. = 6·64. Kimbosan, Japan.

Belonesite. Perhaps $MgMoO_4$. In minute acicular crystals at Vesuvius.

VII. SALTS OF ORGANIC ACIDS.

Oxalates, Mellates.

Whewellite. Calcium oxalate, $CaC_2O_4 + H_2O$. In small colorless monoclinic crystals. From Saxony, with coal.

Oxammite. Ammonium oxalate, $(NH_4)_2C_2O_4 + 2H_2O$. From the guano of the Guañape Islands, Peru.

Humboldtine. Hydrous ferrous oxalate, $2FeC_2O_4 + 3H_2O$. Color yellow. From near Bilin, Bohemia.

Mellite. Hydrous aluminium mellate, $Al_2C_{12}O_{12} + 18H_2O$. In square pyramids; also massive, granular. G. = 1·55–1·65. Color honey-yellow. Occurs in brown coal in Thuringia, Bohemia, etc.

VIII. HYDROCARBON COMPOUNDS.

The Hydrocarbon compounds in general, with few exceptions, are *not homogeneous substances*, but mixtures, which by the action of solvents or by fractional distillation may be separated into two or more component parts. They are hence not definite mineral species and do not strictly belong to pure Mineralogy, rather, with the recent gums and resins, to Chemistry or, so far as they are of practical value, to Economic Geology. In the following pages they are treated for the most part with great brevity.

---

1. Simple Hydrocarbons. Chiefly members of the Paraffin Series C_nH_{2n+2}.

Scheererite. In whitish monoclinic crystals. Perhaps a polymer of marsh-gas (CH_4). Found in brown coal at Uznach, Switzerland.

Hatchettite. Mountain Tallow. In thin plates, or massive. Like soft wax. Color yellowish. Ratio of C to H = nearly 1 : 1. From the Coal-measures near Merthyr-Tydvil in Glamorganshire, England.

Paraffin. A native crystallized paraffin has been described as occurring in cavities in basaltic lava near Paterno, Sicily.

Ozocerite Mineral wax pt. Like wax or spermaceti in appearance and consistency. Colorless to white when pure; often leek-green, yellowish, brownish yellow, brown. Essentially a paraffin, and consisting chiefly of one of the higher members of the series. Occurs in beds of coal, or associated bituminous deposits, as at Slanik, Moldavia; Boryslaw in the Carpathians. Also occurs in southern Utah on a large scale.

Zietrisikite, *Chrismatite*, *Urpethite* are near ozocerite.

Fichtelite. In white monoclinic tabular crystals. Perhaps C_5H_8. Occurs in thin layers of pine wood from peat-beds near Redwitz, in the Fichtelgebirge, Bavaria. *Hartite* has a similar occurrence.

Napalite. A yellow bituminous substance of the consistency of shoemaker's wax. C_3H_4. From the Phœnix mercury mine in Pope Valley, Napa county, California.

---

2. Oxygenated Hydrocarbons.

Amber. Bernstein, *Germ.* In irregular masses, with conchoidal fracture. H. = 2–2·5. G. = 1·096. Luster resinous. Color yellow, sometimes reddish, brownish, and whitish, often clouded, sometimes fluorescent. Transparent to translucent. Heated to 150° begins to soften, and finally melts at 250°–300°. Ratio for C, H, O = 40 : 64 : 4.

Part of the so-called amber is separated mineralogically as *succinite* (yielding succinic acid). Other related fossil resins from many other regions (e. g , the Atlantic coast of the United States) have been noted. Some of them have been called *retinite*, *gedanite*, *glessite*, *rumänite*, *simetite*, *krantzite*, *chemawinite*, etc.

Amber occurs abundantly on the Prussian coast of the Baltic from Dantzig to Memel; also on the coasts of Denmark, Sweden, and the Russian Baltic provinces. It is mined extensively, and is also found on the shores cast up by the waves after a heavy storm. Amber and the similar fossil resins are of vegetable origin, altered by fossilization; this is inferred both from its native situation with coal, or fossil wood, and from the occurrence of insects incased in it. Amber was early known to the ancients, and called *ἤλεκτρον*, *electrum*, whence, on account of its electrical susceptibilities, has been derived the word *electricity*.

Copalite, or Highgate resin, is from the London blue clay. It is like the resin copal in hardness, color, luster, transparency, and difficult solubility in alcohol. Color clear pale yellow to dirty gray and dirty brown. Emits a resinous aromatic odor when broken.

The following are oxygenated hydrocarbons occurring with coal and peat deposits, etc.:

Bathvillite. Occurs in dull, brown, porous lumps in the torbanite or Boghead coal (of the Carboniferous formation) adjoining the lands of Torbane Hill, Bathville, Scotland.

It may be an altered resin, or else material which has filtrated into the cavity from the surrounding torbanite.

TASMANITE. In minute reddish brown scales disseminated through a laminated shale; average diameter of scales about 0·03 in. Not dissolved at all by alcohol, ether, benzene, turpentine, or carbon disulphide, even when heated. Remarkable as yielding 5·3 p. c. sulphur. From the river Mersey, north side of Tasmania; the rock is called *combustible shale*.

DYSODILE. In very thin folia, flexible, slightly elastic; yellow or greenish gray. Analysis gave 2·3 p. c. sulphur and 1·7 p. c. nitrogen. From lignite deposits at Melili, Sicily, and elsewhere.

GEOCERITE. A white, wax-like substance, separated from the brown coal of Gesterwitz, near Weissenfels. *Geomyricite* and *geocerellite* are other products from the same source.

LEUCOPETRITE. Also from the Gesterwitz brown coal. Between a resin and wax in physical characters.

PYRORETINITE. From brown coal near Aussig, Bohemia.

DOPPLERITE. In elastic or partly jelly-like masses; brownish black. An acid substance, or mixture of different acids, related to humic acid. Ratio for C, H, O, nearly 10 : 12 : 5. From peat beds near Aussee in Styria, etc.

IDRIALITE. Occurs with the cinnabar of Idria. In the pure state white and crystalline in structure. In nature found only impure, being mixed with cinnabar, clay, and some pyrite and gypsum in a brownish-black earthy material, called, from its combustibility and the presence of mercury, *inflammable cinnabar* (*Quecksilberbranderz*).

POSEPNYTE. Occurs in hard, brittle plates or nodules, light green in color. From the Great Western mercury mine, Lake Co., California. See also napalite, p. 543.

The following are still more complex native hydrocarbon compounds of great importance from an economic standpoint.

Petroleum. NAPHTHA; PETROLEUM. Mineral oil. Kerosene. Erdöl, Bergöl, Steinöl, *Germ.*

PITTASPHALT; Maltha. Mineral Tar. Bergtheer *Germ.*

Liquids or oils, in the crude state of disagreeable odor; varying widely in color, from colorless to dark yellow or brown and nearly black, the greenish-brown color the most common; also in consistency from thin flowing kinds to those that are thick and viscous; and in specific gravity from 0·6 to 0·9. Petroleum, proper, passes by insensible gradations into *pittasphalt* or *maltha* (viscid bitumen); and the latter as insensibly into *asphalt* or solid bitumen.

Chemically, petroleum consists for the most part of members of the paraffin series, C_nH_{2n+2}, varying from marsh gas, CH_4, to the solid forms. The olefines, C_nH_{2n}, are also present in smaller amount. This is especially true of the American oils. Those of the Caucasus have a higher density, the volatile constituents are less prominent, they distill at about 150° and contain the benzenes, C_nH_{2n-6}, in considerable amount. There are present also members of the series C_nH_{2n-8}. The German petroleum is intermediate between the American and the Caucasian. The Canadian petroleum is especially rich in the solid paraffins.

Petroleum occurs in rocks or deposits of nearly all geological ages, from the Lower Silurian to the present epoch. It is associated most abundantly with argillaceous shales, sands, and sandstones, but is found also permeating limestones, giving them a bituminous odor, and rendering them sometimes a considerable source of oil. From these oleiferous shales, sands and limestones the oil often exudes, and appears floating on the streams or lakes of the region, or rises in oil springs. It also exists collected in subterranean cavities in certain rocks, whence it issues in jets or fountains whenever an outlet is made by boring. The oil which fills the cavities has ordinarily been derived from the subjacent rocks; for the strata in which the cavities exist are frequently barren sandstones. The conditions required for the production of such subterranean accumulations would be therefore a bituminous oil-bearing or else oil-producing stratum at a greater or less depth below; cavities to receive the oil; an overlying stratum of close-grained shale or limestone, not allowing of the easy escape of the naphtha vapors.

The two regions which now furnish the chief part of the petroleum are, first in importance, western Pennsylvania, with parts of New York and Ohio, and, second, the Baku region on the Caspian Sea, at the eastern end of the Caucasus. The oil has been known to exist at the latter locality since early times, but only since 1876 has its economic importance been recognized. Petroleum is also obtained in this country in West Virginia; near Cañon City, Colorado; and in California, especially in Los Angeles, Ventura and Santa Cruz counties. Numerous localities where it occurs in limited amount have been noted in other States. In Canada, oil is produced in Lambton county, Ontario. Other oil-producing regions are found in Burma, Japan, New Zealand, etc.

Asphaltum. Mineral Pitch. Asphalt, Bergpech, Erdpech, *Germ.*

Asphaltum, or mineral pitch, is a mixture of different hydrocarbons, part of which are oxygenated. Its ordinary characters are as follows: Amorphous. G. = 1–1·8; sometimes higher from impurities. Luster like that of black pitch. Color brownish black and black. Odor bituminous. Melts ordinarily at 90° to 100°, and burns with a bright flame. Soluble mostly or wholly in oil of turpentine, and partly or wholly in ether; commonly partly in alcohol. The more solid kinds graduate into the pittasphalts or mineral tar, and through these there is a gradation to petroleum. The fluid kinds change into the solid by the loss of a vaporizable portion on exposure, and also by a process of oxidation, which consists first in a loss of hydrogen, and finally in the oxygenation of a portion of the mass. The action of heat, alcohol, ether, naphtha and oil of turpentine, as well as direct analyses, show that the so-called asphaltum from different localities is very various in composition.

Asphaltum belongs to rocks of no particular age. The most abundant deposits are superficial. But these are generally, if not always, connected with rock deposits containing some kind of bituminous material or vegetable remains. Some of the noted localities of asphaltum are the region of the Dead Sea, or Lake Asphaltites, whence the most of the asphaltum of ancient writers; a lake on Trinidad, 1½ m. in circuit, which is hot at the center, but is solid and cold toward the shores, and has its borders over a breadth of ¾ m. covered with the hardened pitch with trees flourishing over it; at various places in South America; in California, near the coast of St. Barbara; also in smaller quantities, elsewhere.

ELATERITE. Elastic Bitumen. Mineral Caoutchouc. Soft, elastic, sometimes much like india-rubber; occasionally hard and brittle. Color usually dark brown. Found at Castleton in Derbyshire, and elsewhere.

ALBERTITE. Differs from ordinary asphaltum in being only partially soluble in oil of turpentine, and in its very imperfect fusion when heated. H. = 1–2. G. = 1·097. Luster brilliant, pitch-like; color jet-black. Occurs filling an irregular fissure in rocks of the Lower Carboniferous in Nova Scotia.

GRAHAMITE. Resembles albertite in its pitch-black, lustrous appearance. H. = 2. G. = 1·145. Soluble mostly in oil of turpentine; partly in ether, naphtha or benzene; not at all in alcohol; wholly in chloroform and carbon disulphide. Melts only imperfectly, and with a decomposition of the surface. Occurs in W. Virginia, about 20 m. S. of Parkersburg, filling a fissure in a Carboniferous sandstone.

GILSONITE, also called *Uintahite* or Uintaite. A variety of asphalt from near Ft. Duchesne, Utah, which has found many applications in the arts. Occurs in masses several inches in diameter, with conchoidal fracture; very brittle. H. = 2–25; G. = 1·065–1·070. Color black, brilliant and lustrous; streak and powder a rich brown. Fuses easily in the flame of a candle and burns with a brilliant flame, much like sealing-wax. Named after Mr. S. H. Gilson of Salt Lake City.

Mineral Coal. Compact massive, without crystalline structure or cleavage; sometimes breaking with a degree of regularity, but from a jointed rather than a cleavage structure. Sometimes laminated; often faintly and delicately banded, successive layers differing slightly in luster. Fracture conchoidal to uneven. Brittle; rarely somewhat sectile. H. = 0·5–2·5. G. = 1–1·80. Luster dull to brilliant, and either earthy, resinous or submetallic. Color black, grayish black, brownish black, and occasionally iridescent; also sometimes dark brown. Opaque. Infusible to subfusible; but often becoming a soft, pliant or paste-like mass when heated. On distillation most kinds afford more or less of oily and tarry substances, which are mixtures of hydrocarbons and paraffin.

The varieties recognized depend partly (1) on the amount of the volatile ingredients afforded on destructive distillation; or (2) on the nature of these volatile compounds, for ingredients of similar composition may differ widely in volatility, etc.; (3) on structure, luster and other physical characters.

Coal is in general the result of the gradual change which has taken place in geological history in organic deposits, chiefly vegetable, and its form and composition depend upon the extent to which this change has gone on. Thus it passes from forms which still retain the original structure of the wood (peat, lignite) and through those with less of volatile or bituminous matter to anthracite and further to kinds which approach graphite.

1. **ANTHRACITE.** Glanzkohle *Germ.* H. = 2–2·5. G. = 1·32–1·7. Luster bright, often submetallic, iron-black, and frequently iridescent. Fracture conchoidal. Volatile matter after drying 3–6 p. c. Burns with a feeble flame of a pale color. The anthracites of Pennsylvania contain ordinarily 85–93 per cent. of carbon; those of South Wales, 88–95; of France, 80–83; of Saxony, 81; of southern Russia, sometimes 94 per cent. Anthracite graduates through semi-anthracite into bituminous coal, becoming less hard and containing more volatile matter; and an intermediate variety is called *free-burning* anthracite.

2. **BITUMINOUS COAL.** Burns in the fire with a yellow, smoky flame, and gives out on distillation hydrocarbon oils or tar; hence the name *bituminous*. The *ordinary* bituminous coals contain from 5–15 p. c. (rarely 16 or 17) of oxygen (ash excluded); while the so-called *brown coal* or *lignite* contains from 20–36 p. c., after the expulsion, at 100°, of 15–36 p. c. of water. The amount of hydrogen in each is from 4–7 p. c. Both have usually a bright, pitchy, greasy luster, a firm compact texture, are rather fragile compared with anthracite, and have G. = 1·14–1·40. The *brown* coals have often a brownish-black color, whence the name, and more oxygen, but in these respects and others they shade into ordinary bituminous coals. The ordinary bituminous coal of Pennsylvania has G. = 1·26–1·37; of Newcastle, England, 1·27; of Scotland, 1·27–1·32; of France, 1·2–1·33; of Belgium, 1·27–1·3. The most prominent kinds are the following:

(*a*) *Caking* or *Coking Coal.* A bituminous coal which softens and becomes pasty or semi-viscid in the fire. This softening takes place at the temperature of incipient decomposition, and is attended with the escape of bubbles of gas. On increasing the heat, the volatile products which result from the ultimate decomposition of the softened mass are driven off, and a coherent, grayish-black, cellular or fritted mass (*coke*) is left. Amount of coke left (or part not volatile) varies from 50–85 p. c.

(*b*) *Non-Caking Coal.* Like the preceding in all external characters, and often in ultimate composition; but burning freely without softening or any appearance of incipient fusion. There are all gradations between caking and non-caking bituminous coals.

(*c*) *Cannel Coal* (Parrot Coal). A variety of bituminous coal, and often caking; but differing from the preceding in texture, and to some extent in composition, as shown by its products on distillation. It is compact, with little or no luster, and without any appearance of a banded structure; and it breaks with a conchoidal fracture and smooth surface; color dull black or grayish black. On distillation it affords, after drying, 40 to 66 p. c. of volatile matter, and the material volatilized includes a large proportion of burning and lubricating oils, much larger than the above kinds of bituminous coal; whence it is extensively used for the manufacture of such oils. It graduates into oil-producing coaly shales, the more compact of which it much resembles. *Torbanite* is a variety of cannel coal of a dark brown color, from Torbane Hill, near Bathgate, Scotland; also called *Boghead Cannel.*

(*d*) *Brown Coal* (Braunkohle *Germ.*, Lignite). The prominent characteristics of brown coal have already been mentioned. They are non caking, but afford a large proportion of volatile matter; sometimes pitch-black, but often rather dull and brownish black. G. = 1·15–1·3. Brown coal is often called *lignite.* But this term is sometimes restricted to masses of coal which still retain the form of the original wood. *Jet* is a black variety of brown coal, compact in texture, and taking a good polish, whence its use in jewelry.

Coal occurs in beds, interstratified with shales, sandstones, and conglomerates, and sometimes limestones, forming distinct layers, which vary from a fraction of an inch to 30 feet or more in thickness. In the United States, the anthracites occur east of the Alleghany range, in rocks that have undergone great contortions and fracturings, while the bituminous coals are found extensively in many States farther west, in rocks that have been less disturbed; and this fact and other observations have led geologists to the view that the anthracites have lost their bitumen by the action of heat. The *origin* of coal is mainly vegetable, though animal life has contributed somewhat to the result. The beds were once beds of vegetation, analogous, in most respects, in mode of formation to the peat beds of modern times, yet in mode of burial often of a very different character. This vegetable origin is proved not only by the occurrence of the leaves, stems and logs of plants in the coal, but also by the presence throughout its texture, in many cases, of the forms of the original fibers; also by the direct observation that peat is a transition state between unaltered vegetable débris and brown coal, being sometimes found passing completely into true brown coal. *Peat* differs from true coal in want of homogeneity, it visibly containing vegetable fibers only partially altered; and wherever changed to a fine-textured homogeneous material, even though hardly consolidated, it may be true brown coal.

For an account of the chief coal fields, as also of the geological relations of the different coal deposits, reference is made to works on Economic Geology.

APPENDIX A.

ON THE DRAWING OF CRYSTAL FIGURES AND OF PROJECTIONS.

In the representation of crystals by drawings, the object may be either to show the entire form in perspective or to give simply a projection of the faces upon a single plane. The first of these cases is the more important, and must be treated here in some detail. Two points are to be noted in regard to it. In the first place, in the drawings of crystals the point of view is supposed to be at an infinite distance, and it follows from this that all lines which are parallel on the crystal appear *parallel* in the drawing.

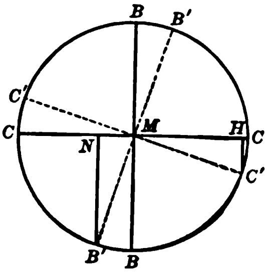
In the second place, in all ordinary cases, it is the complete ideal crystal which is represented, that is, the crystal with its full geometrical symmetry as explained on pp. 9 to 11 (cf. note on p. 11).

PROJECTION OF THE AXES.

The projection of the axes of a crystal is the first step preliminary to the drawing of the form of the crystal itself. The projection of the axes in the isometric system, which are equal and intersect at right angles, is here first given. The projection of the axes in the other systems, with the exception of the hexagonal, may be obtained by varying the lengths of the projected isometric axes, and also, when oblique, their inclinations, as shown beyond.

Isometric System.—When the eye is directly in front of a face of a cube, neither the sides nor top of the crystal are visible, nor the faces that may be situated on the intermediate edges. On turning the crystal a few degrees from right to left a side lateral face is brought in view, and by elevating the eye slightly the terminal face becomes apparent. In the following demonstration the angle of revolution is designated δ, and the angle of the elevation of the eye, ϵ. Fig. 989 represents the normal position of the horizontal axes, supposing the eye to be in the direction of the axis BB; BB is seen as a mere point, while CC appears of its actual length. On revolving the whole through a number of degrees equal to BMB′ (δ) the axes have the position exhibited in the dotted lines. The projection of the semiaxis MB is now lengthened to MN, and that of the semiaxis MC is shortened to MH.

989.



If the eye be elevated (at any angle, ϵ), the lines B′N, BM, and C′H will be projected respectively below N, M, and H, and the lengths of these projections (which we may designate b'N, bM, and cH) will be directly proportional to the lengths of the lines B′N, BM, and C′H.

It is usual to adopt such a revolution and such an elevation of the eye as may be expressed by a simple ratio between the projected axes. The ratio between the two axes, MN : MH, as projected after the revolution, is designated by $1 : r$; and the ratio of b'N to MN by $1 : s$. Suppose r to equal 3 and s to equal 2, then proceed as follows:

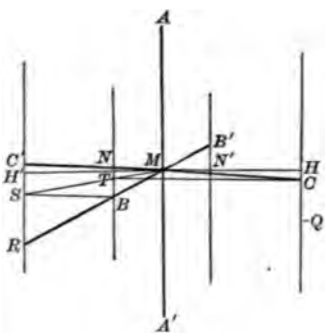
Draw two lines AA′, H′H (Fig. 990), intersecting one another at right angles. Make MH = MH′ = b. Divide HH′ into 3 (r) parts, and through the points, N, N′, thus determined, draw perpendiculars to HH′. On the left hand vertical, set off, below H′, a part H′R, equal to $\frac{1}{s}b = \frac{1}{2}$ H′M; and from R draw RM, and extend the same to the vertical N′. B′B is the projection of the front horizontal axis.

Draw BS parallel with MH′ and connect SM. From the point T in which SM intersects BN, draw TC parallel with MH. A line (CC′) drawn from C through M, and extended to the left vertical, is the projection of the side horizontal axis.

Lay off on the right vertical a part HQ equal to $\frac{1}{8}$ MH, and make MA = MA′ = MQ;

AA′ is the vertical axis. If, as here, $r = 3$, and $s = 2$, then $\delta = 18° 26'$, and $\epsilon = 9° 28'$, for $\cot \delta = r$, and $\cot \epsilon = rs$.

990.



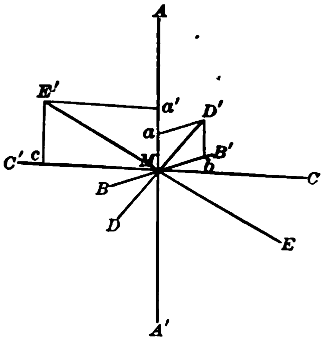
It is desirable to go through the above construction with care to insure all possible accuracy. The axes thus obtained, say twice the length here represented, may be drawn on a suitable card and preserved for future use. Whenever needed, they can be readily transferred to a sheet of paper by pricking through the terminal and central points. In each case, before the axes so obtained are used, they should be tested to make sure that the respective semiaxes either side of the central point M are equal.

Tetragonal and Orthorhombic Systems.—The axes AA′, CC′, BB′, constructed in the manner described, are equal and at right angles to each other. The projection of the axes of a tetragonal crystal is obtained by simply laying off, with a scale of proportional parts, on MA and MA′ taken as units, the value of the vertical axis ($\acute{c}$) for the given species. Thus for zircon, where $\acute{c} = 0{\cdot}64$, we must lay off 0·64 of MA above M and the same length below.

For an orthorhombic crystal, where the three axes are unequal, the length of $\acute{c}$ must as before be laid off above and below from M, and that of $\breve{a}$ in front and behind M, on BB′. It is usual to make the side axis $\mathrm{MC} = \bar{b} = 1$.

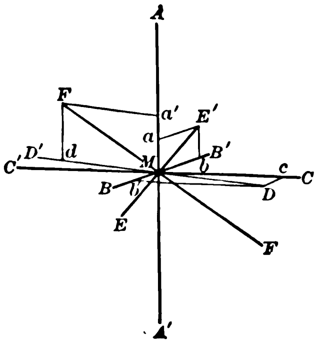
Monoclinic System.—The axes $\acute{c}$ and $\breve{a}$ in the monoclinic system are inclined to one another at an oblique angle $= \beta$. To project this inclination, and thus adapt the isometric axes to a monoclinic form, lay off (Fig. 991) on the axes MA, $\mathrm{M}a = \mathrm{MA} \times \cos \beta$, and on the axis BB′ behind M, $\mathrm{M}b = \mathrm{MB} \times \sin \beta$. From the points b and a, draw lines parallel respectively with the axes AA′ and BB′, and from their intersection D′, draw through M, D′D, making MD = MD′. The line DD′ is the clinodiagonal, and the lines AA, C′C, DD′ represent the axes in a monoclinic solid in which $a = b = c = 1$. The points a and b and the position of the axis DD′ will vary with the angle β. The relative values of the axes may be given them as above explained; that is, if $\bar{b} = 1$, lay off in the direction of MA and MA′ a line equal to $\acute{c}$, and in the direction of MD and MD′ a line equal to $\breve{d}$, etc.

991.



Triclinic System.—The vertical sections through the horizontal axes in the triclinic system are obliquely inclined; also the inclination of the axis a to each axis b and c, is oblique. In the adaptation of the isometric axes to the triclinic forms, it is therefore necessary, in the first place, to give the requisite obliquity to the mutual inclination of the vertical sections, and afterwards to adapt the horizontal axes. The inclination of these sections we may designate A, and as heretofore, the angle between a and b, γ, and a and c, β. BB′ is the analogue of the brachydiagonal, and CC of the macrodiagonal. An oblique inclination may be given the vertical sections, by varying the position of either of these sections. Permitting the brachydiagonal section ABA′B′ to remain unaltered, we may vary the other section as follows:

992.

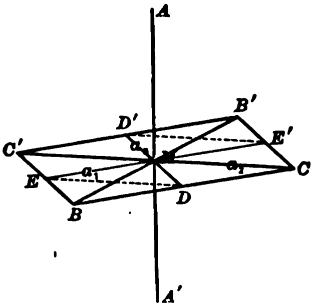


Lay off (Fig. 992) on MB, $\mathrm{M}b' = \mathrm{MB} \times \cos \mathrm{A}$, and on the axis C′C (to the right or left of M, according as the acute angle A is to the right or left), $\mathrm{M}c = \mathrm{MC} \times \sin \mathrm{A}$; completing the parallelogram Mb' Dc, and drawing the diagonal MD, extending the same to D′ so as to make MD′ = MD, we obtain the line DD′; the vertical section passing through this line is the correct macrodiagonal section. The inclination of a to the new macrodiagonal DD′ is still a right angle; as also the inclination of a to b, their oblique inclinations may be given them as follows: Lay off on MA (Fig.

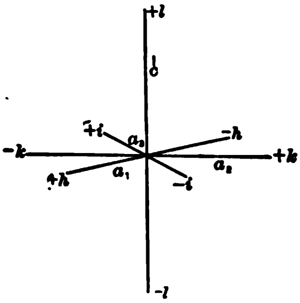
992), $Ma = MA \times \cos \beta$, and on the axis BB′ (brachydiagonal), $Mb = MB' \times \sin \beta$. By completing the parallelogram Ma, $E'b$, the point E′ is determined. Make ME = ME; EE′ is the projected brachydiagonal. Again lay off on MA, $Ma' = MA \times \cos \alpha$, and on MD′, to the left, $Md = MD' \times \sin \alpha$. Draw lines from a' and d parallel to MD and MA; F′, the intersection of these lines, is one extremity of the macrodiagonal; and the line FF′, in which MF = MF′, is the macrodiagonal. The vertical axis AA′ and the horizontal axes EE′ (brachydiagonal) and FF′ (macrodiagonal) thus obtained, are the axes in a triclinic form, in which $a = b = c = 1$. Different values may be given these axes, according to the method heretofore illustrated.

Hexagonal System.—The simplest method of obtaining the axes for the hexagonal system is as follows: We start with the isometric axial cross (Fig. 990) and change it so that the front axis (MB, Fig. 993) shall have a length equal to 1·732 ($= \sqrt{3}$) times its original length. When the extremities of the lines CC′ and BB′ are joined a rhomb will be formed having the angles at C and C′ equal to 120°. Now draw through the middle points of MB, MB′ lines parallel to CC′, and the resulting figure, CDEC′D′E′, will be a regular hexagon. The lines joining its angles, namely, CC′, DD′, EE′, will be the lateral axes required; these are shown in Fig. 994, repeated from p. 65. It only remains to give the vertical axis the length required by the case in hand.

993.



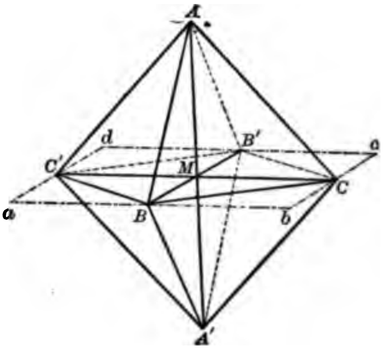
994.



Drawing of Simple and Complex Crystals.

Simple Forms.—When the axial cross has been constructed for the given species, the *octahedron* in the isometric system and the *unit pyramid* in the other systems are obtained at once by joining the extremities of each of the lateral axes with those of the vertical axis This is illustrated for the isometric system by Fig. 995 Here, as in all cases, the lines which fall in front are drawn strongly, while those behind are simply dotted.

995.



For the *diametral prism* draw through B, B′, C, C′, of the projected axes of any species (Fig. 995), lines parallel to the axes CC′, BB′, until they meet; they make the parallelogram, *abcd*, which is a transverse section of the prism, parallel to the base. Through *a*, *b*, *c*, *d* draw lines parallel and equal to the vertical axis, making the parts above and below these points equal to the vertical semi-axis. Then, connect the extremities of these lines by lines parallel to *ab*, *bc*, *cd*, *da*, and the figure will be that of the diametral prism, corresponding to the axes projected.

In the case of the isometric system (Fig. 995), this diametral prism is the cube whose faces are represented by the letter *a* (100), Fig. 70, p. 34; in the tetragonal system it is the prism *a* (100), *c* (001), Fig. 149, p. 54; in the orthorhombic, monoclinic and triclinic systems the faces have the symbols *a* (100), *b* (010), *c* (001), as shown in Figs. 275, 312, 338.

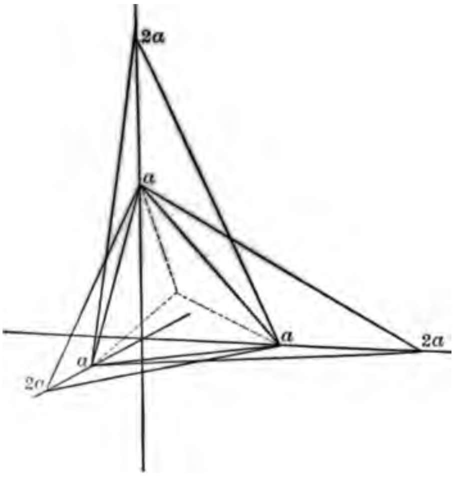
The *unit vertical prism* in the tetragonal, orthorhombic, and clinometric systems may be projected by drawing lines parallel to the vertical axis AA′ through B, C, B′, C′, making the parts above and below these points equal, and then connecting the extremities of these lines by lines parallel to BC, CB', B'C', C'B. The plane BCB'C' is a transverse section of such a prism parallel to its base. This prism is bounded by the faces *m* (110), *c* (001). Cf. Figs. 150, 276, 318.

Other prisms in the orthorhombic, monoclinic and triclinic systems, as (210), (120), etc., are drawn in the same way, only that the lateral axes must be adapted to each case. Thus for (210) the axis *b* has double the unit value characteristic of the given species; for (120) it has half this value (or, otherwise expressed, the axis *a* is to be doubled), and so on.

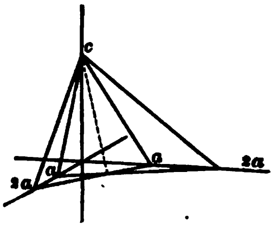
In the tetragonal system the prisms (210), (310), etc., have eight faces (cf. Fig. 152, p. 54). Therefore, *e.g.* for (210), first draw in the plane of the lateral axes lines from the unit length of each axis to the double of that adjoining (+ and −); the intersections of these eight lines are points through which lines must be drawn vertically (parallel to *c*), corresponding to the edges lettered *y* in Fig. 152. For the hexagonal system the construction of the three prisms is so similar to those described as to need no further explanation.

Other simple forms are constructed on much the same principle. The points are first to be determined at which the respective faces cut the axes. Then light construction lines are drawn in each of the axial planes connecting these points, and at the same time the intersection-points noted for each pair of adjoining faces. From these last the actual intersection lines of the given form are obtained.

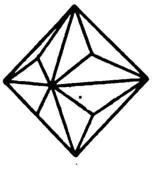
996.



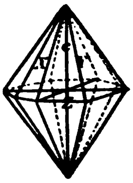
998.



997.



999.



Figs. 996 to 999 will serve as illustrations. The form Fig. 997 is the trisoctahedron (221). The three front upper faces of this have the symbols 221, 212, 122 (cf. Fig. 88, p. 38). For them the axial intersections are (see the explanation on pp. 23, 24) as follows:

$$\tfrac{1}{2}a_1 : \tfrac{1}{2}a_2 : 1a_3 = 1a_1 : 1a_2 : 2a_3;$$
$$\tfrac{1}{2}a_1 : 1a_2 : \tfrac{1}{2}a_3 = 1a_1 : 2a_2 : \ a_3;$$
$$1a_1 : \tfrac{1}{2}a_2 : \tfrac{1}{2}a_3 = 2a_1 : \ a_2 : \ a_3.$$

Here the axes a_1, a_2, a_3 are, as always, taken in the *a*, *b*, *c*, order (cf. Fig. 55, p. 22). Fig. 996 shows each of the three planes projected on the axes, and their respective intersection-edges are seen at once to be the dotted lines starting from the points lettered *a*. The completion of the figure involves no further difficulty. It is to be noted, however, that it is not necessary to repeat the full construction for each octant, since the principle of symmetry with respect to the three axial planes, that is, along lines parallel to each of the axes, comes in to simplify the work. In practice, it is well to construct the front half and use the symmetry to complete the part behind, which is usually drawn in dotted lines. The symmetry, in any case, is a most valuable check on the accuracy of the work.

Another illustration is given by Figs. 998, 999 of the ditetragonal pyramid (122) of the tetragonal system (cf. Fig. 166, p. 58). This requires no additional explanation.

Complex Forms.—When it is required to draw not only the faces of a single form embraced under the same symbol, but also those of a number of forms modifying one another, a somewhat different process is found desirable. It is possible, indeed, to construct a complex figure in the way just mentioned, each plane being laid off on the given axes, and its intersection-edges with adjoining planes determined by two points, always in the axial sections, which it has in common with each of them. In this way, however, the figure will soon become so complex as to be extremely perplexing, and thus lead to error and consequent loss of time.

The process of determining the direction of the intersection-edges is much simplified if the expression giving the ratio of the intercepts on the axes for each plane is so transformed (by dividing by the coefficient of the vertical axis) that the value for the vertical axis shall be unity (that is, in general equal to $\dot{c}$). The extremity of the vertical axis (+ or −) is then *one point* of intersection for any two planes, and the other point will always be in the plane of the lateral axes.

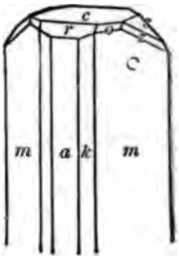
As an example of the transformation called for, suppose 324 to be the symbol of a given face, its intercepts on the axes *a*, *b*, *c* would be (Art. 34) $\frac{1}{3}a : \frac{1}{2}b : \frac{1}{4}c$. This put into the form required for the present purpose becomes (by muptiplying by 4),

$$\tfrac{4}{3}a : 2b : c.$$

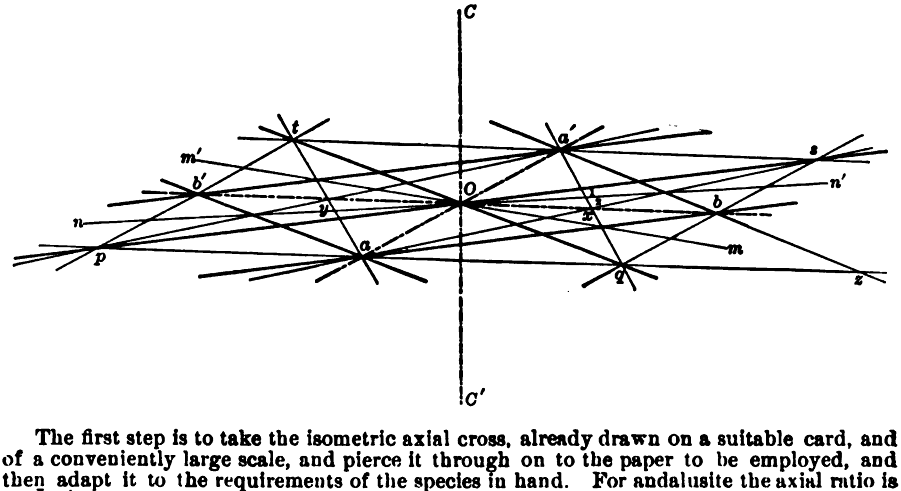
It will be noted that the expression thus obtained is not ordinarily that which corresponds to the Naumann symbols, for with them the length of a lateral axis (usually *a*) is taken as the unit.

Example.—The explanation of the method of drawing crystals can best be described by use of a concrete example. Suppose that it is required to draw an orthorhombic crystal (andalusite) of prismatic habit (Fig. 1000), showing the faces *a* (100), *c* (001), *m* (110), *r* (101), *s* (011), *o* (111). *s* (121). It is evident that an indefinite number of figures may be made, including the faces mentioned, and yet of very different appearance according to the relative size of each. It is usually desirable, however to represent the actual appearance of the crystal in nature, only in ideal symmetry, hence it is important in all cases to have a sketch of the crystal to be represented, showing the relative development of the different faces. If this sketch is made with a little care, so as to exhibit also the parallelism of the intersection-edges in the occurring zones, it will give material aid. The zones, it is to be noted, are a great help in drawing figures of crystals, and they should be carefully studied, since the common direction of the intersection-edge, once determined for any two faces in it, will answer for all others.

1000.



1001.



The first step is to take the isometric axial cross, already drawn on a suitable card, and of a conveniently large scale, and pierce it through on to the paper to be employed, and then adapt it to the requirements of the species in hand. For andalusite the axial ratio is $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}99 : 1 : 0{\cdot}70$. Hence the vertical axis must be 0·7 of its isometric length, but (in this case) the lateral axis calls for no change.

The next step is to draw on the plane of the lateral axes (Fig. 1001) a line giving the trace of each face as it is needed. Each line is obtained from the expression of the axial intercepts transformed in the manner already explained, so that the value for $\dot{c}$ shall be unity. For the faces of the prism, *m* (110), the required lines are *ps* and *qt* (Fig. 1001). Obviously their intersection-edges are parallel to the vertical axis, while their intersections with the base *c* (001) are parallel to *ps* and *qt*. Similarly the mutual intersection-edges for the faces of the prism *k* (210) and the pinacoid *a* (100) will be parallel to CC′.

Further, the corresponding lines for the upper faces of the macrodome, *cr*, that is, 101 and $\bar{1}01$, are *pq* and *ts*: those of the faces of the clinodome *s* (011) are *qs* and *pt*; those of the faces of the pyramids *o* (111) are *ab*, *ba′*, *a′b′*, *b′a*; those of the pyramid *s* (121), whose intercepts in the required form are $1a : \frac{1}{2}b : 1c$, are *as*, *qa′*, *a′p*, *ta*. Each of the planes mentioned passes also through C, the extremity of the vertical axis. Therefore, whatever intersection-edge is called for is given at once by the figure. For example, that for the faces *s* (121) and *s* (011) is the line joining C with *s*, since the lines *as* and *qs* representing these planes intersect at *s* and all planes pass through C; further, the same direction is that of the intersection-edge of *m* (110), *s* (121), since the trace of *m* (110) also passes through the point *s*. So also the intersection-edge of *o* (111) and *s* (121) will be the line joining C and *a*, and the same line is that required for *r* (101) and *o* (111); that of *r* and k''' ($2\bar{1}0$) is given by the line joining C and *s*, since the trace of k''', or *mm′* (Fig. 1001; cf. Fig. 1002), if produced, meets that of *r* (101) or *pq* at *s*.

The above explanation will show how the required intersection-edges can be obtained as needed. In the practical use of the method it is customary to begin with the predominating form and then add the modifying faces in succession. That is, in the case in hand, the prism *m* would be drawn terminated by *c*; then perhaps the pinacoid *a* added; then the prism *k* (210), and afterward the terminal faces.

The actual figure is usually made on the sheet of paper below the axial projection (Fig. 1001), the directions of the inter section-edges being carefully transferred by means of a triangle sliding against the side of another triangle or a ruler. The figure should be made considerably larger than as finally required, since only in this way is sufficient accuracy attainable. The final figure of the required size is readily accomplished by photo-engraving, if the drawing is done clearly and in black lines.

To complete the figure behind, the intersection-lines can be obtained in the same way. It is to be noted, however, that in the given case (of an orthorhombic crystal) the symmetry can be used to simplify the process, or, if desired, merely to check the work done, since every point in front has a corresponding symmetrical point behind equally distant from the axial plane *bc*, in the direction of the axis *a*. The symmetry right and left relatively to the axial plane *ac* also should be used to test the accuracy as regards the two sides of the figure. When the upper half of the figure (or, if preferred, the front half) is completed, the symmetry, as noted, is usually employed in the completion of the remainder, since (in this case) every line in front above has one parallel and equal to it behind below. In the case of crystals of lower grade of symm etry the method is less simple, and in some instances considerable ingenuity is called for, but practice will serve to give facility.

ON THE DRAWING OF TWIN CRYSTALS.

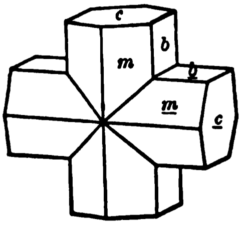
Twinned Crystals.—In order to project a compound or twinned crystal it is generally necessary to obtain first the axes of the second individual, or semi-individual, in the position in which they are brought by the revolution of 180°. This is accomplished in the following manner: In Fig. 1002 a compound crystal of staurolite is represented, in which twinning has taken place (1) on an axis normal to (032), and in Fig. 1003 this is shown again with also twinning on an axis normal to (232). The second method of twinning being the more general, is of the greater importance for the sake of example. In Fig. 1004 *cc′*, *bb′*, *aa′* represent the rectangular axes of staurolite $\breve{a} : \bar{b} : \dot{c} = 0{\cdot}47 : 1 : 0{\cdot}68$). The twinning-plane ($2\bar{3}2$) has the position MNR. It is first necessary to construct a normal from the center O to this plane. If perpendiculars be drawn from the center O to the lines MN, NR, MR, they will meet them at the points *x*, *y*, *z*, dividing each line into segments proportional to the squares of the adjacent axes;* or $Nx : Mx = \overline{ON}^2 : \overline{OM}^2$. In this way the points *x*, *y*, *z* are fixed, and lines drawn from any two of them to the opposite angles R, N, or M will fix the point T. A line joining T and O is normal to the plane (MNR = $2\bar{3}2$). Furthermore, it is obvious that if a revolution of 180° about TO take place, that every point in the plane MNR will remain equally distant from T. Thus the point M will take the place

---

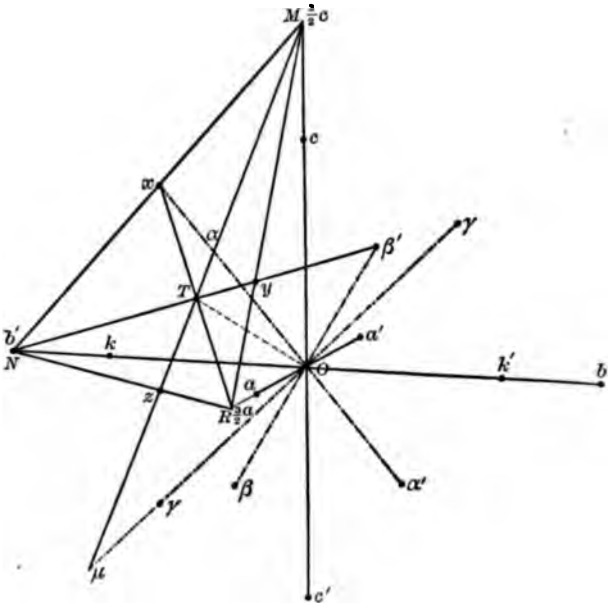
* This is true, since the axial angles are right angles. In the Monoclinic System two of the axial intersections are perpendicular, and they are sufficient to allow of the determination of the point T as above.

μ(MT = Tμ), the point b' the place β' (NT = Tβ'), and so on. The lines joining these points μ, β', x, and the common center O will be the new axes corresponding to MO, NO, RO. In order to obtain the unit axes corresponding to $\dot{c}$, $\bar{b}$, $\acute{a}$ it is merely necessary to draw through c a line parallel to MTu, meeting μO at γ, then $\gamma O\gamma$ is the new vertical axis corresponding to cOc'; also, $\beta O\beta'$ corresponds to bOb', and $\alpha O\alpha'$ corresponds to aOa'. These three axes, then, are the axes for the second individual in its twinned position; upon them, in the usual way, the new figure may be constructed and then transferred to its proper position with reference to the normal crystal.

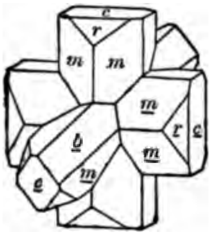
1002.



1004.



1003.



For the second method of twinning, when the axis is normal to (032), the construction is more simple. It is obvious that the axis is the line Ox, and using this, as before, the new axes are found; $\kappa O\kappa'$ corresponds to cOc' (sensibly coinciding with bb'), since c (001) ∧ 032 = 45° 41′, and so on.

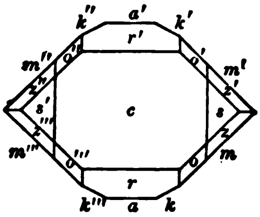
In many cases the simplest method is to construct first the normal crystal, then draw through its center the twinning-plane and the axis of revolution, and determine the angular points of the reversed crystal on the principle alluded to above: that by the revolution every point remains at the same distance from the axis, measured in a plane at right angle to the axis. Thus in Fig. 384, p. 126, when the scalenohedron has been drawn, since the twinning-plane is the basal plane, each angular point, by the revolution of 180°, obtains a position equidistant from this plane and directly below it. In this way each angular point is determined, and the compound crystal is completed in a moment.

DRAWING OF PROJECTIONS.

Horizontal Projections.—It is often convenient to have, instead of a drawing of a complete crystal, a so-called horizontal projection of its faces upon a single plane. The plane selected is usually that normal to the prismatic zone—in other words, that parallel to the base of all crystals except those of the clinometric system; Figs. 30, 32, 34, 36, 39, on pp. 15, 16, are examples. Other planes may also be taken with advantage in certain cases, as, for example, the clinodiagonal axial plane with monoclinic crystals. Fig. 326, p. 103, represents such a projection of a crystal of epidote.

The drawing of these projections is readily accomplished by one who has mastered the method already described (p. 551); it is further illustrated here by Figs. 1005, 1006. The projection given (Fig. 1005) is that of the figure of andalusite shown in Fig. 1000.

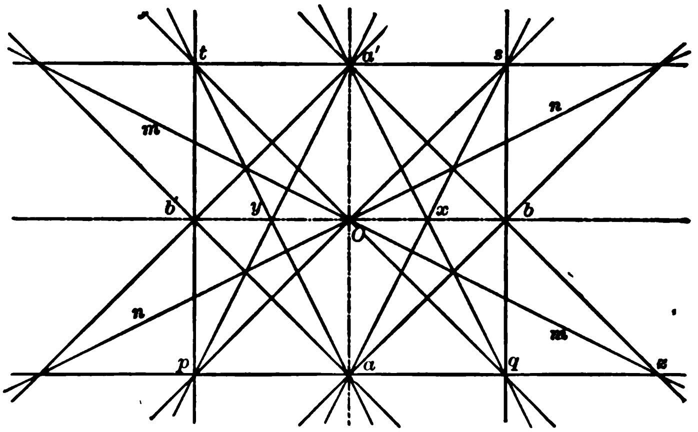
1005.



In Fig. 1006 the dotted lines *aa'*, *bb'* represent the lateral axes (here sensibly equal). The projection of the unit prism *m* (110) on this plane gives the lines *ps* and *qt*; of the prism, *k* (210), the lines *nn'* and *mm'*; of the pyramid, *z* (121), the lines *as*, *a'q*, *a'p*, and *at*, etc.

The intersection-edges for any two planes will be given by the line drawn through *c* (the extremity of the vertical axis as projected, common to all planes), and also through the point where the lines representing the given planes intersect. Thus the faces *z* and *s* are represented in the projection by the lines *as* and *qs* respectively. These lines meet at *s*; hence the intersection-direction for the two faces will be the line drawn through O and *s*.

1006.



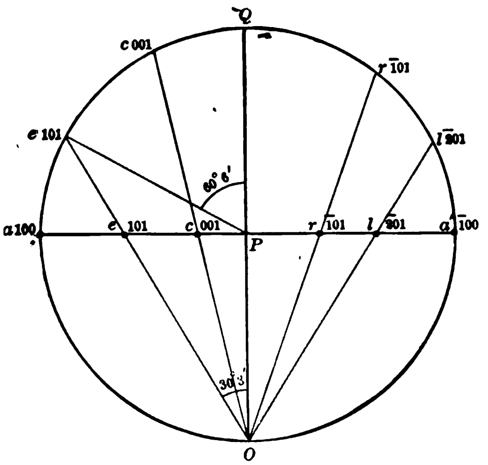
The projection shown in Fig. 1006, when each face of a crystal is represented by a line on a given plane, usually that normal to the prismatic zone (vertical axis), was proposed by Quenstedt, and is known as the *Quenstedt Projection*; it was made by him the basis of an elaborate system of crystallography. It will be noticed that zones here are represented by points, since all the lines representing the faces of a given zone must pass through the same point in the plane of projection; this is still true mathematically of lines which are parallel.

Spherical Projection.—Various methods have been suggested and are in use for representing the positions of the faces of a crystal, especially with respect to their zonal relations, the angles between them, etc.; these do not, however, attempt to give a picture of the crystal itself. One of these—the Quenstedt projection—represented by Fig. 1006, has already been spoken of. Another valuable method is that of Goldschmidt, which he makes the base of his ingenious and practical system (see references on p. 117).

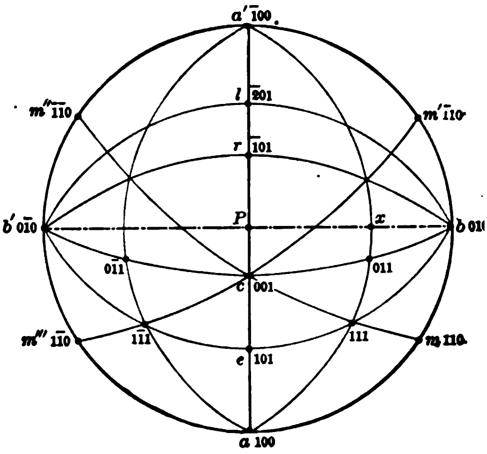
The most serviceable method and the only one used in the present book is the spherical projection described in Arts. **39** to **42** and of which examples are given in the pages following (see Fig. 110, p. 41; 171, p. 58, etc.). The method of construction needed has been explained in Art. **40**, so far as it applies to the orthometric systems.

For the *monoclinic system* it is to be noted (cf. Fig. 327, p. 103, and Fig. 1008) that while the poles of the prismatic faces still lie on the circumference of the circle and can be fixed at once with a protractor, and while all the orthodomes ($h0l$) lie in the diameter from *a* (100) to *a'* ($\bar{1}00$) at 90° from *b* (010), the base *c* (001) is *not* the middle point of the circle, as in the projections of the orthometric systems. The position of *c* can, however, be readily fixed, since the complement of the angle *ac* ($100 \wedge 001 = \beta$) gives its angular distance from the middle point of the diameter *aa'* (P in Fig. 1008); and this distance on the projection is proportional to the tangent of half this angle in terms of the given radius. So also the position of any orthodome whose angular distance from *a* (100), *a'* ($\bar{1}00$), or *c* (001), is known can be fixed on the sphere of projection in the same way.

1007.



1008.



Instead of using the tangent of the half angles with a scale of proportional parts the distances may be readily constructed without calculation. Thus for epidote we have

ae, 100 ∧ 101 = 29° 54';
ac, 100 ∧ 001 = 64° 37';
a'r, $\bar{1}00$ ∧ $\bar{1}01$ = 51° 41';
a'l, $\bar{1}00$ ∧ $\bar{2}01$ = 25° 57'.

Draw a circle with the given radius (Fig. 1007) and measure off on the circumference from *a* (100) and *a'* ($\bar{1}00$) the successive angles given. Then join the points so fixed with the point *O*, the opposite extremity of the diameter at right angles to *aPa'*, which is supposed to be the position of the eye in this method of projection. The points where these lines intersect the diameter *aPa'* give the position of *e* (101), *c* (001), *r* ($\bar{1}01$), *l* (201), to be used for the projection of Fig. 1008.

When the positions of the poles of the orthodomes of the given crystal are fixed in the diameter *aa'* (Fig. 1008), and also those of the prisms on the circumference of the circle, it is obvious that the pole of any other face can be determined by drawing the proper circular arcs. Thus the arc 010, 101, $0\bar{1}0$ and that 110, 001, $\bar{1}\bar{1}0$ together determine the position of 111, and so on for any pyramid. Again, the arc 100, 111, $\bar{1}00$ and 010, 001, $0\bar{1}0$ determine the position of 011. It is to be noted, however, that for sake of accuracy it may be better to fix the pole of 011, or any given clinodome, independently. If (Fig. 1008) a diameter be drawn connecting *b* (010) and *b'* ($0\bar{1}0$), it is clear that the angular distance *bx* and hence P*x* (P*b* = 90°) can be obtained at once by the solution of a single right-angled triangle in which the hypothenuse (010 ∧ 011 or in general 001 ∧ 0*kl*) is known and also the angle at *b*—the last being equal to 90°—*ac*. When the point *x* is known the circular arc *axa'* determines the position of 011, and so in general of any clinodome. Fig. 1007 makes it clear at once why, as stated in Art. **40**, the tangent of half the angle from the central point of the sphere gives the position of any pole, the radius of the circle being taken as unity. It is seen here (Fig. 1007) that the actual angle, for example 60° 6', for *e* (101) at the center is one-half the corresponding angle (30° 3') at the circumference; further, the distance P*e* is proportional to tan 30° 3' (tan ½ 60° 6'), where the radius *a*P is equal to unity.

In the *triclinic system* the spherical projection can be drawn by an extension of the method just described. It is assumed that the angles between the pinacoids are known, *ab*, *ac*, *bc* : also the angles of the triangle *abc* which are the supplements of the axial angles α, β, γ. In the first place the positions of *a* (100), *b* (010), and of the prisms are fixed by the protractor on the circumference of the circle. Now draw through *aa'* a diameter and at right angles to this another diameter, meeting the circumference at two points B, B′, 90° from *a* and *a′*. A circular arc drawn through BB′ and *c* (001) will cut the diameter *aa′* at a point K, whose distance from the center P can be calculated in a right-angled spherical triangle in which the hypothenuse (*ac*) and the adjacent angle at *a* are known. Hence the position of K is fixed. Again, draw the diameter *bb′*, and at right angles to it another diameter, *AA′*. If L is the point on *bb′* where it is cut by the circular arc through *bcb′*, the distance PL can be similarly calculated. With K and L both fixed, it is easy to draw *aca′* and *bcb′*, and thus determine the position of *c*. After the zone circles *aca′* and *bcb′* have been drawn, the position of any dome (*h*0*l* or 0*kl*) can be similarly found by a single calculation, and as the prisms have been fixed it is easy to locate any required pyramid.

On the general method of projection applicable to triclinic crystals, see Groth, Phys. Kryst., p. 579, *et seq.*, and Liebisch, Geometr. Kryst., p. 124, *et seq.*

APPENDIX B.

TABLES TO BE USED IN THE DETERMINATION OF MINERALS.

This Appendix contains a series of tables, more or less complete, of minerals arranged according to certain prominent crystallographic or physical characters. These, it is believed, will be of service not only to the student, but also to the skilled mineralogist. Table I., of Minerals arranged according to System of Crystallization, is intended to embrace all well-recognized species, though those of relatively greater importance, especially as regards occurrence, are indicated by being printed in heavier type.

The other tables make no claim to completeness, being limited often to common and important species.

For an exhaustive system of Determinative Tables based particularly upon blowpipe and chemical characters, the student is referred to the work of Professors Brush and Penfield, mentioned on p. 256.

I. MINERALS ARRANGED ACCORDING TO THEIR SYSTEM OF CRYSTALLIZATION.

The following lists are intended to include all well-recognized species, whose crystallization is known, arranged according to the system to which they belong, and further classified by their luster and specific gravity; the hardness is also given in each case.

I. CRYSTALLIZATION ISOMETRIC.*

A. LUSTER UNMETALLIC.

	Specific Gravity.	Hardness.
Sal Ammoniac (p. 319)..	1·53	1·5–2
Kalinite (p. 535)........	1·75	2–2·5
Faujasite (p. 460).......	1·92	5
Sylvite (p. 319)........	1·98	2
Halite (p. 318)..........	2·14	2·5
Hydrophilite (p. 321)...	2·2	
Sodalite (p. 412).........	2·14–2·30	5·5–6
Analcite (p. 460)........	2·2–2·3	5–5·5
Noselite (p. 413)........	2·25–2·4	5·5
Northupite (p. 364).....	2·38	3·5–4
Haüynite (p. 412)......	2·4–2·5	5·5–6
Leucite (p. 381)........	2·45–2·50	5·5–6
Lazurite (p. 413)........	2·38–2·45	5–5·5
Sulphohalite (p. 521)....	2·49	3·5
Ralstonite (p. 323)......	2·58	4·5
Voltaite (p. 537)........	2·79	3–4
Langbeinite (p. 523).....	2·83	
Zunyite (p. 414)........	2·87	7
Pollucite (p. 382)........	2·90	6·5
Boracite (p. 518).......	2·9–3	7
Pharmacosiderite(p.513)	2·9–3	2·5
Nitrobarite (p. 517). ...	3·2	
Fluorite (p. 320)........	3·2	4
Helvite (p. 414)........	3·16–3·36	6–6·5
Garnet (p. 415).........	3·3–4·3	6·5–7·5
Rhodizite (p. 518).......	3·4	8
Danalite (p. 414)........	3·43	5·5–6
Hauerite (p. 301)........	3·46	4
Diamond (p. 271)... ...	3·52	10
Spinel (p. 338)..........	3·5–4·1	8
Periclase (p. 331)........	3·67	6
Arsenolite (p. 330)......	3·7	1·5
Schorlomite (p. 419)....	3·81–3·88	7–7·5
Hercynite (p. 339)	3·9–3·95	7·5–8
Sphalerite (p. 291)......	3·9–4·1	3·5–4
Nantokite (p. 317)....	3·93	2–2·5
Marshite (p. 317)........	5·6?	
Alabandite (p. 292).....	3·95–4·04	3·5–4
Perovskite (p. 487)......	4·03	5·5
Berzeliite (p. 495).......	4·08	5
Gahnite (p. 339)	4·0–4·6	7·5–8
Pyrochlore (p. 489)......	4·2–4·36	5–5·5
Koppite (p. 489).........	4·45–4·56	
Zirkelite (p. 346)........	4·71	5·5
Hatchettolite (p. 489)....	4·8–4·9	5
Lewisite (p. 516)........	4·95	5·5
Atopite (p. 516).........	5·03	5·5–6
Percylite, Boleite (p. 322)	5·08	2·5
Mauzeliite (p. 516)	5·11	6–6·5
Manganosite (p. 332)....	5·18	5–6
Senarmontite (p. 330)....	5·2–5·3	2–2·5
Embolite (p. 319)........	5·3–5·4	1–1·5
Cerargyrite (p. 319)....	5·55	1–1·5
Miersite (p. 319)........	5·6	
Microlite (p. 489)........	5·5–6·1	5·5
Iodobromite (p. 319)....	5·71	1–1·5
Bromyrite (p. 319)......	5·8–6	2–3
Cuprite (p. 331).........	5·85–6·15	3·5–4
Eulytite (p. 414)	6·11	4·5
Bunsenite (p. 332).......	6·4	5·5
Monimolite (p. 496).....	6·58; 7·29	5–6

---

* Some pseudo-isometric species are here included. Species with submetallic luster are placed under B, but some species are included in both lists.

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Hauerite (p. 301)........	3·46	4	Canfieldite (p. 316)......	6·28	2·5–3
Sphalerite (p. 291)......	3·9–4·1	3·5–4	**Ullmannite** (p. 302).....	6·2–6·7	5–5·5
Alabandite (p. 292)......	3·95–4·04	3·5–4	**Smaltite**, Chloanthite (p. 301)...............	6·4–6·6	5·5–6
Cubanite (p. 297)........	4·0–4·1	4	Skutterudite (p. 307)....	6·7–6·86	6
Dysanalyte (p. 488).....	4·13	5–6	Willyamite (p. 302).....	6·87	5·5
Stannite (p. 315)	4·3–4·52	4	Polyargyrite (p. 315)....	6·97	2·5
Chromite (p. 341).......	4·3–4·57	5·5	Laurite (p. 302)..........	7·0	7·5
Binnite (p. 308)..........	4·5	2·5–3	**Argentite** (p. 288).......	7·2–7·36	2–2·5
Tennantite (p. 313).....	4·4–4·49	3–4	**Iron** (p. 281)... ..., ...	7·3–7·8	4–5
Tetrahedrite (p. 312)..	4·4–5·1	3–4	**Galena** (p. 287)..........	7·4–7·6	2·5–3
Magnesioferrite (p. 341).	4·57–4·65	6–6·5	Eucairite (p. 289).......	7·5	2·5
Pentlandite (p. 298)....	4·6	3·5–4	Metacinnabarite (p. 292).	7·8	3
Polydymite (p. 296).....	4·5–4·8	4·5	Clausthalite (p. 288)....	7·6–8·8	2·5–3
Jacobsite (p. 341).......	4·75	6	Naumannite (p. 288)....	8·0	2·5
Sychnodymite (p. 296)..	4·76		Altaite (p. 288)..........	8·16	3
Linnaeite (p. 297).......	4·8–5	5·5	Tiemannite (p. 292).....	8·2–8·5	2·5
Carrollite (p. 297)... ...	4·85	5·5	Hessite (p. 289)	8·3–8·9	2·5–3
Bixbyite (p. 348).........	4·95	6–6·5	**Copper** (p. 278)..........	8 8–8·9	2·5–3
Pyrite (p. 300)..........	4·95–5·10	6–6·5	**Uraninite** (p. 521).......	9–9·7	5·5
Franklinite (p. 341).....	5·07–5·22	6–6·5	**Silver** (p. 278)...........	10·1–11·1	2·5–3
Magnetite (p. 339)......	5·18	6–6·5	Sperrylite (p. 302).......	10·6	6–7
Bornite (p. 297)........	4·9–5·4	3	**Lead** (p. 279)............	11·4	1·5
Gersdorffite (p. 302).....	5.6–6·2	5·5	Palladium (p. 281)......	11·3–11·8	4·5–5
Cuprite (p. 331)..	5·85–6·15	3·5–4	**Amalgam** (p. 279)......	13·7–14·1	3–3·5
Brongniardite (p. 309)...	5·95	3·5	**Platinum** (p. 280).......	14–19	4–4·5
Corynite (p. 302)........	5·95–6·08	4·5–5	Gold (p. 275)...........	15·6–19·3	2·5–3
Argyrodite (p. 316)......	6·1–6·2	2·5	Iridium (p. 280)........	22·6–22 8	6–7
Cobaltite (p. 301).......	6–6·3	5·5			

II. CRYSTALLIZATION TETRAGONAL.

A. Luster Unmetallic.

Mellite (p. 542)..........	1·64	2–2·5	**Torbernite** (p. 515).....	3·4–3·6	2–2·5
Darapskite (p. 517)......			Trippkeite (p. 516).. ...		
Apophyllite (p. 452)....	2·3–2·4	4·5-5	**Octahedrite** (p. 346)....	3·8–3·95	5·5–6
Löweite (p. 535)	2·38	2·5–3	**Rutile** (p. 345)	4·18–4·25	6–6·5
Ecdemite (p. 516).......	6·9–7·1	2·5–3	**Xenotime** (p. 494)......	4·45–4·56	4–5
Sarcolite (p. 426).......	2·54–2·93	6	Powellite (p. 541)	4·53	3·5
Marialite (p. 426).......	2·57	5·5–6	**Thorite** (p. 430)	4·4–5 4	4·5–5
Mizzonite (Dipyre), (426)	2·62	5·5–6	Fergusonite (p. 490)	4·4–5·8	5·5–6
Wernerite (Scapolite), (p 426)...............	2·66–2·73	5 5–6	**Zircon** (p. 428)...........	4·68–4·7	7·5
Meionite (p. 425)........	2·70–2·74	5·5–6	Romeite (p. 516).......	4·71	5·5–6
Edingtonite (p. 460)	2·70	4–4·5	Sipylite (p. 490)	4·89	6
Chiolite (p. 321)	2·84–2·99	3·5–4	Ganomalite (p. 408).....	5·74	3
Melilite (p. 426)	2·9–3·1	5	**Scheelite** (p. 540).......	5·9–6·1	4·5–5
Gehlenite (p. 427).......	2·9–3·1	5·5–6	**Phosgenite** (p. 364).....	6–6·09	2·75-3
Meliphanite (p. 407)	3·01	5–5·5	**Calomel** (p. 317)........	6·48	1–2
Sellaite (p. 321)	2·97–3·15	5	**Wulfenite** (p. 541)......	6·7–7·0	2·75-3
Zeunerite (p. 515).......	3·2	2–2·5	**Cassiterite** (p. 344)......	6·8–7·1	6–7
Pinnoite (p. 520)	3·27–3·37	3–4	Matlockite (p. 322)......	7·2	2·5–3
Vesuvianite (p. 428)....	3·35–3·45	6·5	Tapiolite (p. 492)........	7·36–7·5	6
			Stolzite.................	7·87–8·13	2·75–3

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Chalcopyrite (p. 297)	4·1–4·3	3·5–4	Polianite (p. 345)	4·84–5·0	6–6·5
Rutile (p. 345)	4·18–4·25;5·2	6–6·5	Reinite (p. 542)	6–6·4	4
Fergusonite (p. 490)	4·4–5·8	5·5–6	Hauchecornite (p. 295)	6·4	5
Hausmannite (p. 342)	4·7–4·86	5–5·5	Tapiolite (p. 492)	7·36–7·5	6
Braunite (p. 343)	4·75–4·82	6–6·5	Plattnerite (p. 346)	8·5	5–5·5

III. CRYSTALIZATION HEXAGONAL.*

Rhombohedral species are distinguished by a letter R.

A. Luster Unmetallic.

Ice (p. 331)	0·9	1·5	Jarosite (p. 537) R.	3·20	2·5–3·5
Cyprusite? (p. 537)	1·75	2	Raimondite (p. 536)	3·20	3
Ettringite (p. 538)	1·75	2–2·5	Hamlinite (p. 503) R.	3·23	4·5
Thaumasite (p. 483)	1·88	3·5	Pyrochroite (p. 351) R.	3·26	2·5
Gmelinite (p. 459) R.	2·04–2·17	4·5	Jeremejevite (p. 518)	3·28	6·5
Coquimbite (p. 535) R.	2·09	2–2·5	**Dioptase** (p. 424) R.	3·28–3·35	5
Utahite (p. 536) R			Svanbergite (p. 516) R.	3·30	5
Chabazite (p. 458) R.	2·08–2·16	4–5	Cronstedtite (p. 475) R.	3·35	3·5
Levynite (p. 459) R.	2·09–2·16	4–4·5	Hematolite (p. 507) R.	3·35	3·5
Hydronephelite? (p. 463).	2·26	4·5–6	Connellite (p. 530)	3·36	3
Soda niter (p. 517) R.	2·26	1·5–2	Mesitite (p. 359) R.	3·33–3·42	3·5–4
Tridymite (p. 328)	2·28–2·33	7	**Rhodochrosite** (359) R.	3·45–3·60	3·5–4·5
Brucite (p. 351) R.	2·38–2·4	2·5	Svabite (p. 501)	3·52	5
Cancrinite (p. 411)	2·42–2·5	5–6	**Siderite** (p. 359) R.	3·83–3·88	3·5–4
Microsommite (p. 411)	2·44	6	Rhabdophanite (p.509) R.	3·94–4·01	3·5
Kaliophilite (p. 410)	2·49	6	Wurtzite (p. 295)	3·98	3·5–4
Carphosiderite? (p.536) R	2·50	4–4·5	**Corundum** (p. 333) R.	3·95–4·10	9
Metavoltine (p. 537)	2·53	2·5	**Willemite** (p. 422) R.	3·94–4·19	5·5
Chalcophyllite (p.511) R.	2·44–2·66	2	Sphærocobaltite (361) R.	4·02–4·13	4
Nephelite (p. 409)	2·55–2·65	5·5–6	Melanocerite (p. 407) R.	4·13	5–6
Hanksite (p. 530)	2·56	3–3·5	Tritomite (p. 407) R.	4·20	5·5
Ferronatrite (p. 536) R.	2·56	2	Nordenskiöldine (518) R.	4·20	5·5–6
Milarite (p. 369)	2·57	5·5–6	Caryocerite (p. 407) R.	4·29	5–6
Aphthitalite (p. 523) R.	2·64	3–3·5	Parisite (p. 364)	4·36	4·5
Quartz (p. 324) R.	2·65	7	**Smithsonite** (p. 360) R.	4·30–4·45	5
Beryl (p. 405)	2·64–2·7;2·80	7·5–8	Beudantite (p. 516) R.	4–4·3	3·5–4·5
Eucryptite (p. 410)	2·67		Plumbogummite? (p.514)	4–4·9	4–5
Alunite (p. 537) R.	2·67	3·5–4	Cappelenite (p. 407)	4·41	6–6·5
Penninite (pseu.) (p.474) R	2·6–2·85	2·25	**Greenockite** (p. 294)	4·9–5·0	3–3·5
Calcite (p. 354) R	2·71	3	**Hematite** (p. 334) R.	4·9–5·3	5·5–6·5
Alumian (p. 530)	2·74	2–3	Xanthoconite (p. 315) R.	5–5·2	2
Catapleiite (p. 407)	2·8	6	**Zincite** (p. 332)	5·4–5·7	4–4·5
Dolomite (p. 357) R.	2·8–2·9	3·5–4	**Proustite** (p. 311) R.	5·6	2–2·5
Martinite (p. 510) R	2·89		Iodyrite (p. 319)	5·6–5·7	1–1·5
Eudialyte (p. 407) R.	2·91–2·93	5–5·5	Fluocerite (p. 322)	5·7–5·9	4
Ankerite (p. 358) R.	2·95–3·1	3·5–4	**Pyrargyrite** (p. 311) R.	5·85	2·5
Phenacite (p. 423) R.	2·97–3·0	7·5–8	Penfieldite (p. 322)		
Tourmaline (p. 447) R.	2·98–3·20	7–7·5	Barysilite (p. 408)	6·11	3
Magnesite (p. 358) R.	3·0–3·12	3·5–4·5	Tysonite (p. 321)	6·13	4·5–5
Pyrosmalite (p. 424) R.	3·06–3·19	4–4·5	**Pyromorphite** (p. 499)	6·5–7·1	3·5–4
Friedelite (p. 424) R.	3·07	4–5	**Vanadinite** (p. 500)	6·66–6·86	3
Spangolite (p. 530) R.	3·14	2	**Mimetite** (p. 500)	7·0–7·25	3·5
Apatite (p. 497)	3·17–3·28	5	**Cinnabar** (p. 293) R.	8·0–8·2	2–2·5

---

* Some pseudo-hexagonal species are included.

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Graphite (p. 273) R....	2·1–2·2	1–1·5	**Pyrargyrite** (p. 311) R..	5·85	2·5
Chalcophanite (p. 352)R.	3·91	2·5	**Tellurium** (p. 275) R...	6·1–6·3	2–2·5
Ilmenite (p 336) R......	4·5–5	5–6	Allemontite (p. 275) R...	6·2	3·5
Covellite (p. 294)........	4·6	1·5–2	**Antimony** (p 275) R...	6·7	3–3·5
Pyrrhotite (p. 296).....	4·6	3·5–4·5	Tetradymite (p. 284) R..	7·2–7·6	1·5–2
Molybdenite (p. 285)...	4·7–4·8	1–1·5	**Niccolite** (p. 295)......	7·3–7·67	5–5·5
Långbanite (p. 446)	4·92	6·5	Breithauptite (p. 296)...	7·54	5·5
Hematite (p. 334) R ...	5·2–5·3	5·5–6·5	**Cinnabar** (p. 298) R....	8·0–8·2	2–2·5
Millerite (p. 295) R....	5·3–5·65	3–3·5	**Bismuth** (p. 275) R.....	9·7–9·8	2–2·5
Arsenic (p. 274) R......	5·6–5·7	3·5	**Iridosmine** (p. 280) R...	19·3–21·1	6–7

IV. CRYSTALLIZATION ORTHORHOMBIC.

A. Luster Unmetallic.

Teschemacherite (p. 364)	1·45	1·5	**Talc** (p. 479)...........	2·7–2·8	1–1·5
Thermonatrite (p. 366)..	1·5–1·6	1–1·5	**Beryllonite** (p. 496).....	2·84	5·5–6
Carnallite (p. 322).......	1·6	1–1·5	**Haidingerite** (p. 510)....	2·85	1·5–2·5
Struvite (p. 507)........	1·65–1·7	2	Strengite (p. 510).......	2·87	3–4
Epsomite (p. 533).......	1·75	2–2·5	**Lawsonite** (p. 447)......	3·08	7·5–8
Mascagnite (p. 523).....	1·77	2–2·5	**Humite** (p. 443)	3·1–3·2	6–6·5
Nesquehonite (p. 366)...	1·84	2·5	**Anthophyllite** (p. 398)..	3·1–3·2	5·5–6
Goslarite (p. 533).......	1·9–2·1	2–2·5	**Andalusite** (p. 432).....	3·16–3·2	7·5
Morenosite (p. 533)......	2·0	2–2·25	**Enstatite** (p. 384)	3·15–3·3	5·5
Sulphur (p. 278)........	2·07	1·5–2·5	**Autunite** (p. 515).......	3·05–3·19	2–2·5
Lindackerite (p. 516)....	2·0–2·5	2–2·5	**Monticellite** (p. 422)....	3·03–3·25	5–5·5
Newberyite (p. 510).....	2·10	3–3·5	**Eosphorite** (p. 514)......	3·11–3·15	5
Niter (p. 517)	2·09–2·14	2	Childrenite (p. 518).....	3·18–3·24	4·5–5
Sideronatrite (p. 537)....	2·15	2–2·5	**Sillimanite** (p. 433).....	3·24	6–7
Fluellite (p. 322)........	2·17	3	**Scorodite** (p. 509)......	3·1–3·3	3·5–4
Natrolite (p. 461).......	2·20–2·25	5–5·5	Lossenite (p. 516).......		
Okenite? (p. 452)........	2·28	4–5·5	**Forsterite** (p. 422)......	3·2–3·33	6–7
Felsöbanyite (p. 537)....	2·33	1·5	Dumortierite (p. 449)....	3·26	7
Thomsonite (p. 462)....	2·3–2·4	5–5·5	Kornerupine (p. 451) ...	3·27	6·5
Wavellite (p. 512)......	2·33	3·5–4	**Zoisite** (p. 437)..........	3·25–3·37	6–6·5
Hambergite (p. 518)....	2·35	7·5	**Dufrenite** (p. 506)......	3·23–3·4	3·5–4
Pirssonite (p. 366)........	2·35	3·35	**Chrysolite** (p. 420).....	3·27–3·37	6·5–7
Sulfoborite (p. 521).....	2·38–2·45	4	Warwickite (p. 518).....	3·35	3–4
Fischerite (p. 512)	2·46	5	Euchroite (p. 511).......	3·39	3·5–4
Peganite (p. 512).........	2·50	3–3·5	Astrophyllite (p. 487)....	3·3–3·4	3
Elpidite (p. 407).........	2·52–2·59	6·5–7	**Diaspore** (p. 348).......	3·3–3·5	6·5–7
Howlite ? (p. 519).......	2·55	3·5	Natrophilite (p. 496)	3·41	4·5–5
Prehnite (p. 442).......	2·8–2·95	6–6·5	Cenosite (p. 483)	3·41	5·5
Anhydrite (p. 528).....	2·90–2·98	3–3·5	Gerhardtite (p. 517)	3·43	2
Aragonite (p. 361)......	2·94	3·5–4	**Hypersthene** (p. 385)...	3·4–3·5	5·5
Spodiosite? (p. 502).....	2·94	5	Uranospinite (p. 515)....	3·45	2–3
Leucophanite (p. 407)...	2·96	4	Guarinite (p. 487).......	3·49	6
Danburite (p. 430)......	2·97–3·02	7–7·25	**Calamine** (p. 446).......	3·4–3·5	4·5–5
Tyrolite (p. 511)........	3·0–3·1	1·5	Lithiophilite (p. 496)....	3·42–3·56	4·5–5
Harstigite (p. 442)......	3·05	5·5	**Topaz** (p. 431)...........	3·4–3·65	8
Reddingite (p. 508)......	3·10	3–3·5	Langite (p. 536)	3·49	2·5–3
Bertrandite (p. 446)	2·6	6–7	Uranocircite (p. 515)....	3·53	
Lanthanite (p. 366).....	2·6	2·5–3	**Triphylite** (p. 496).....	3·52–3·55	4·5–5
Iolite (p. 407)	2·6–2·66	7–7·5	Epididymite (p. 369).. .	3·55	5·5
Thenardite (p. 523).....	2·68–2·69	2–3	Mazapilite (p. 514)......	3·57	4·5
Hopeite (p. 507)........	2·76	2·5–3	Hemafibrite (p. 511)....	3·50–3·65	3
Phosphosiderite (p. 510).	2·76	3·75	**Chrysoberyl** (p. 342) ...	3·5–3·8	8·5

A. LUSTER UNMETALLIC.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Ardennite (p. 445)	3·62	6–7	Pseudobrookite (p. 343)	4·39–4 98	6
Libethenite (p. 504)	3·6–3·8	4	Euxenite (p. 493)	4·6–5	6·5
Staurolite (p. 450)	3·65–3·75	7–7·5	Cerite (p. 447)	4·86	5·5
Strontianite (p. 362)	3·68–3·71	3·5–4	Æschynite (p. 493)	4·93; 5 17	5–6
Bromlite (p. 362)	3·72	4–4·5	Polycrase (p. 493)	4·97–5·04	5–6
Atacamite (p. 322)	3·76	3–3·5	Cotunnite (p. 321)	5·24–5·8	2
Uranophane (p. 483)	3·81–3·9	2·3	Valentinite (p. 330)	5·57	2·5–3
Flinkite (p. 506)	3·87	4–4·5	**Samarskite** (p. 492)	5·6–5·8	5–6
Serpierite (p. 536)			Yttrotantalite (p. 492)	5·5–5 9	5–5·5
Brochantite (p. 530)	3 91	3·5–4	Melanotekite (p. 446)	5·7	6·5
Brookite (p. 347)	3 87–4·07	5·5–6	Ånnerödite (p. 493)	5·7	6
Pinakiolite (p. 518)	3·88	6	Phœnicochroite? (p. 529)	5·75	3–3·5
Celestite (p. 526)	3·95–3·97	3–3·5	Tellurite (p. 330)	5·9	2
Ludwigite (p. 518)	3·91–4·02	5	Descloizite (p. 505)	5 9–6·2	3·5
Knebelite (p. 422)	3·9–4·1	6 5	Kentrolite (p. 446)	6·19	5
Tephroite (p. 422)	4–4·12	5·5–6	**Anglesite** (p. 527)	6·12–6·39	2·75–3
Carminite (496)	4·105	2·5	Pucherite (p. 496)	6·25	4
Göthite (p. 349)	4·0–4·4	5–5·5	**Caledonite** (p. 530)	6·4	2·5–3
Fayalite (p. 422)	4–4·14	6·5	Daviesite (p. 322)		
Olivenite (p. 504)	4·1–4·4	3	Laurionite (p. 322)		3–3·5
Witherite (p. 362)	4·3–4·35	3–3·75	**Cerussite** (p. 363)	6·46–6·57	3–3·5
Adamite (p. 505)	4·34–4·35	3·5	Nadorite (p. 516)	7 02	3·5–4
Barite (p. 524)	4·5	2·5–3·5	Ochrolite (p. 516)		
Derbylite (p. 516)	4·53	5	Mendipite (p. 322)	7–7·1	2·5–3

B. LUSTER METALLIC (AND SUBMETALLIC).

Brookite (p. 347)	3·87–4·07	5·5–6	**Bournonite** (p. 310)	5·7–5·9	2·5–3
Ilvaite (p. 445)	4·0–4·05	5·5–6	**Boulangerite** (p. 309)	5·75–6·0	2·5–3
Sternbergite (p. 290)	4·1–4·2	1–1·5	Hielmite (p. 493)	5·82	5
Manganite (p. 349)	4·2–4·4	4	Diaphorite (p. 309)	5 9	2·5–3
Enargite (p. 315)	4·43–4·45	3	**Glaucodot** (p. 304)	5·9–6·0	5
Stibnite (p. 283)	4·5–4·6	2	**Arsenopyrite** (p. 303)	5·9–6·2	5·5–6
Famatinite (p. 315)	4·57	3·5	Kentrolite (p. 446)	6·19	5
Klaprotholite (p. 308)	4·6	2·5	Aikinite (p. 310)	6·1–6·8	2–2·5
Wittichenite (p. 310)	4·5–5	3·5	Stromeyerite (p. 290)	6·15–6 3	2·5–3
Euxenite (p. 493)	4 6–5	6·5	**Stephanite** (p. 314)	6·2–6·3	2–2·5
Chalcostibite (p. 308)	4·75–5	3–4	Guanajuatite (p. 284)	6 25-6·6	2 5–3·5
Pyrolusite (p. 347)	4·73–4·86	2–2·5	Geocronite (p. 314)	6·3–6·45	2·5
Polymignite (p. 493)	4·77–4·85	6·5	Wolfachite (p. 304)	6·37	4·5–5
Stylotypite (p. 310)	4·8	3	Emplectite (p. 308)	6·3–6 5	2
Marcasite (p. 302)	4·85–4·9	6–6·5	Meneghinite (p. 313)	6·4	2 5
Æschinite (p. 493)	4·93; 5·17	5–6	**Bismuthinite** (p. 284)	6·4–6·5	2
Zinkenite (p. 307)	5 3–5·35	3–3 5	Schapbachite (p. 309)	6·43	3 5
Andorite (p. 308)	5.34		Alloclasite (p. 304)	6·6	4·5
Sartorite (p. 308)	5·39	3	Cosalite (p. 309)	6·4–6·75	2·5–3
Columbite (p. 490)	5·36–6·0	6	**Nagyagite** (p. 305)	6·85–7·2	1–1·5
Sundtite (p. 308)	5·5	3–4	Rammelsbergite (p. 304)	6 9–7·2	5·5–6
Dufrenoysite (p. 309)	5·55	3	Safflorite (p. 304)	6·9–7·3	4·5–5
Chalcocite (p. 290)	5·5–5·8	2·5–3	**Tantalite** (p. 490)	7–7·3	6
Yttrotantalite (p. 492)	5·5–5·9	5–5·5	Löllingite (p. 308)	7·0–7·4	5–5·5
Jamesonite (p. 308)	5·5–6·0	2–3	**Acanthite** (p. 290)	7·2–7·3	2–2·5
Ånnerödite (p. 493)	5·7	6	Krennerite (p. 305)	8 35	
Melanotekite (p. 446)	5·7	6·5	**Dyscrasite** (p. 288)	9·4–9·8	3 5–4

V. CRYSTALLIZATION MONOCLINIC.

A. LUSTRE UNMETALLIC.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Natron (p. 366)	1·44	1–1·5	**Vivianite** (p. 506)	2·58–2·68	1·5–2
Mirabilite (p. 531)	1·48	1·5–2	Syngenite (p. 534)	2·60	2·5
Whewellite (p. 542)		2·5	**Kaolinite** (p. 481)	2·6–2·63	2–2·5
Stercorite (p. 510)	1·615	2	Pharmacolite (p. 510)	2·64–2·73	2–2·5
Aluminite (p. 537)	1·66	1–2	**Clinochlore** (p. 473)	2·65–2·78	2–2·5
Alunogen (p. 535)	1·6–1·8	1·5–2	**Pectolite** (p. 395)	2·68–2·78	5
Borax (p. 520)	1·69–1·72	2–2·5	Augelite (p. 518)	2·7	4·5–5
Boussingaultite (p. 535)	1·70		**Glauberite** (p. 523)	2·7–2·85	2·5–3
Apjohnite? (p. 535)	1·78	1·5	Polyhalite? (p. 535)	2·77	2·5–3
Fibroferrite? (p. 536)	1·84	2–2·5	**Muscovite** (p. 464)	2·76–3	2–2·5
Melanterite (p. 534)	1·90	2	**Lepidolite** (p. 467)	2·8–2·9	2·5–4
Halotrichite? (535)	1·9–2·0		**Biotite** (p. 467)	2·7–3·1	2·5–3
Pickeringite (p. 535)			**Phlogopite** (p. 469)	2·78–2·85	2·5–3
Hydroboracite (p. 521)	1·9–2·0	2	**Prochlorite** (p. 475)	2·78–2·96	1–2
Gay-lussite (p. 366)	1·94	2–3	Hyalophane (p. 378)	2·805	6–6·5
Kröhnkite (p. 536)	1·98	2·5	Ganophyllite (p. 452)	2·84	4–4·5
Diadochite (p. 516)	2·035	3	Zinnwaldite (p. 467)	2·82–3·20	2·5–3
Botryogen (p. 537)	2·04–2·14	2–2·5	Cuspidine (p. 442)	2·86	5–6
Mordenite (p. 458)	2·08	3–4	**Liroconite** (p. 514)	2·88	2–2·5
Kainite (p. 530)	2·07–2·19	2·5–3	**Wollastonite** (p. 394)	2·8–2·9	4·5–5
Quetenite? (p. 538)	2·08–2·14	3	**Pyrophyllite** (p. 482)	2·8–2·9	1–2
Copiapite (p. 536)	2·10	2·5	Prusopite (p. 328)	2·89	4·5
Trona (p. 367)	2·12	2·5–3	Corundophilite (p. 475)	2·90	2·5
Picromerite (p. 535)	2·1–2·2		Isoclasite? (p. 511)	2·92	1·5
Castanite (p. 536)	2·12	3	Carpholite (p. 447)	2·93	5–5·5
Quenstedtite (p. 535)	2·12	2·5	**Datolite** (p. 435	2·9–3·0	5–5·5
Heintzite (p. 520)	2·13	4–5	Pachnolite (p. 323)	2·93–3	3
Hydromagnesite (p. 367)	2·16	3·5	Thomsenolite (p. 323)	2·93–3	2–3
Stilbite (p. 456)	2·16–2·20	3·5–4	**Cryolite** (p. 321)	2·95–3	2·5
Scolecite (p. 462)	2·16–2·4	5–5·5	Mosandrite (p. 487)	2·93–3	4
Brushite (p. 510)	2·21	2–2·5	**Erythrite** (p. 509)	2·95	1·5–2·5
Heulandite (p. 454)	2·18–2·22	3·5–4	Symplesite (p. 508)	2·96	2·5
Darapskite (p. 517)	2·20	2–3	Cabrerite (p. 509)	2·96	2
Phillipsite (p. 455)	2·2	4–4·5	Beraunite (p. 513)	2·98	
Mesolite (p. 462)	2·2–2·4	5	Herderite (p. 503)	2·99–3·01	5
Blödite (p. 535)	2·25	2·5	**Margarite** (p. 470)	2·99–3·08	3·5–4·5
Epistilbite (p. 454)	2·25	4–4·5	**Amphibole** (p. 399)	2·9–3·4	5–6
Gismondite (p. 457)	2·26	4·5	**Lazulite** (p. 506)	3·06	5–6
Laumontite (p. 457)	2·25–2·36	3·5–4	Wagnerite (p. 502)	3·07	5–5·5
Metabrushite (p. 510)	2·29	2·5–3	Xanthophyllite (p. 471)	3·09	4·6
Wellsite (p. 455)	2·28–2·37	4–4·5	Seybertite (p. 471)	3–3·1	4–5
Gypsum (p. 531)	2·31–2·33	1·5–2	Köttigite (p. 509)	3·1	2·5–3
Gibbsite (p. 351)	2·3–2·4	2·5–3·5	**Euclase** (p. 436)	3·10	7·5
Petalite (p. 369)	2·39–2·46	6–6·5	**Glaucophane** (p. 403)	3.10–3·11	6–6·5
Colemanite (p. 519)	2·42	4–4·5	Ludlamite (p. 513)	3·12	3–4
Hautefeuillite (p. 508)	2·435	2·5	Herrengrundite (p. 536)	3·13	2·5
Brewsterite (p. 454)	2·45	5	Churchite? (p. 509)	3·14	3–3·5
Harmotome (p. 456)	2·44–2·5	4·5	**Chondrodite** (p. 443)	3·1–3·2	6–6·5
Hœrnesite (p. 508)	2·47	1	**Clinohumite** (p. 443)	3·1–3·2	6–6·5
Wapplerite? (p. 510)	2·48	2–2·5	Prolectite (p. 443)		
Serpentine (p. 476)	2·50–2·65	2·5–4	**Spodumene** (p. 393)	3·13–3·2	6·5–7
Calcioferrite (p. 514)	2·52–2·53	2·5	Hureaulite (p. 510)	3·185	5
Eudidymite (p. 369)	2·55	6	Johannite (p. 538)	3·199	2–2·5
Orthoclase (p. 370)	2·57	6	**Pyroxene** (p. 387)	3·2–3·6	5–6
Kieserite (p. 531)	2·57	3–3·5	Neptunite (p. 487)	3·23	5–6

A. LUSTER UNMETALLIC.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Johnstrupite (p. 487)....	3·29		**Azurite** (p. 365)........	3·77–3·83	3·5–4
Epidote (p. 438)........	3·25–3·5	6–7	Allactite (p. 506)........	3·83–3·85	4·5
Rosenbuschite (p. 395)..	3·3	5–6	**Allanite** (p. 440)........	3·5–4·2	5·5–6
Trögerite (p. 515).......	3·3		Claudetite (p. 330)......	3·85–4·15	2·5
Ottrelite? (p. 471)........	3·3	6–7	**Malachite** (p. 364)......	3·9–4·03	3·5–4
Clinohedrite (p. 447)....	3·33	5·5	Durangite (p. 503)......	3·94–4·07	5
Jadeite (p. 393)	3·33–3·35	6·5–7	Partschinite (p. 419)....	4·0	6·5–7
Homilite (p. 436).........	3·38	5	**Gadolinite** (p. 436)......	4·0–4·5	6·5–7
Dickinsonite (p. 507)....	3·34	3·5–4	Barylite (p. 408).........	4·03	7
Piedmontite (p. 440)....	3·40	6·5	Tagilite (p. 511).........	4·08	3–4
Wöhlerite (p. 395)........	3·41–3·44	5·5–6	Dihydrite (p. 505).......	4–4·4	4·5–5
Sapphirine (p. 451)......	3 42–3·48	7·5	Sarkinite (p. 502)........	4·18	4–5
Riebeckite (p. 404)......	3·43		Pyrostilpnite (p. 312)....	4·2	2
Fillowite (p. 507).......	3·43	4·5	**Clinoclasite** (p. 505)....	4·19–4·36	2·5–3
Triplite (p. 502)	3·44–3 8	4–5·5	**Kermesite** (p. 305)......	4·5–4·6	1–1·5
Orpiment (p. 282).......	3 4–3 5	1·5–2	Lautarite (p. 517).......	4·59	
Rinkite (p. 487)	3·46	5	**Monazite** (p. 495)......	4·9–5·3	5–5·5
Arfvedsonite (p. 405)...	3·44–3·45	6	**Linarite** (p. 530)	5·3–5·45	2·5
Synadelphite (p. 506)....	3·45–3·50	4·5	Lorandite (p. 308).......	5·53	2–2·5
Titanite (p. 485)........	3·4–3·56	5–5·5	Baddeleyite (p. 346).....	5·5; 6·025	6·5
Acmite (p. 391).........	3·5–3·55	6–6·5	Vauquelinite (p. 529)....	5·8–6·1	2·5–3
Veszelyite (p. 511)......	3·53	3·5–4	**Crocoite** (p. 529).......	5·9–6·1	2·5–3
Låvenite (p. 395).... ...	3·51–3·55	6	Agricolite (p. 419).......	6·0?	
Chloritoid ? (p. 471)....	3·52–3 57	6·5	**Tenorite** (p. 332)........	5·8–6·25	3–4
Keilhauite (p. 487).......	3·52–3·77	6·5	**Leadhillite** (p. 530).....	6·26–6·44	2·5
Dietzeite (p. 517).......	3·70	3–4	**Lanarkite** (p. 530)......	6·3–6·4	2–2·5
Triploidite (p. 502)	3·7	4·5–5	Atelestite (p. 507)... ...	6·4	3–4·5
Realgar (p. 282)	3·6	1·5–2	Fiedlerite (p. 322).......		
Barytocalcite (p. 364)....	3·65	4	**Hübnerite** (p. 539).....	7·2–7·5	5–5·5
Adelite, Tilasite (p. 502).	3·74	5	Raspite (p. 541).........		
Chalcomenite (p. 538)...	3·76				

B. LUSTER METALLIC (AND SUBMETALLIC).

Allanite (p. 440)........	3·5–4·2	5·5–6	**Polybasite** (p. 314).....	6·0–6·2	2–3
Crednerite (p. 343)......	4·9–5·1	4·5	Pearceite (p. 315).......	6·15	3
Miargyrite (p. 308).....	5·1–5 3	2–2·5	**Freieslebenite** (p. 309)..	6·2–6·4	2–2·5
Plagionite (p. 308)......	5 4	2·5	**Jordanite** (p. 313)......	6·39	3
Rittingerite (p. 312).....	5·63	2–2 5	**Wolframite** (p. 539).....	7·2–7·5	5–5·5
Semseyite (p. 309)......	5·95	2–3	**Sylvanite** (p. 304)......	7·9–8·3	1·5–2

VI. CRYSTALLIZATION TRICLINIC.

A. LUSTER UNMETALLIC.

Sassolite (p. 352).........	1·48	1	Fairfieldite (p. 507)......	3·10	3·5
Lansfordite (p. 367).....	1·54	2·5	Messelite (p. 507)........		3·5
Hannayite (p. 510)......	1·89		Chalcosiderite (p. 514)..	3·11	4·5
Amarantite (p. 536).....	2·11	2·5	**Axinite** (p. 441).........	3·27	6·5–7
Chalcanthite (p. 534)....	2·12–2·30	2·5	Hiortdahlite (p. 396)....	3·27	5–5·6
Römerite (p. 536).........	2·17	3–3·5	Babingtonite (p. 396)....	3·35–3·37	5·5–6
Microcline (p. 373).....	2·54–2·57	6–6·5	Celsian (p. 381)	3 37	6–6·5
Albite (p. 377)...........	2·62–2·65	6–6·5	**Rhodonite** (p. 395)......	3·4–3·68	5·5–6·5
Oligoclase (p. 378)......	2·65–2·67	6–6·5	Trimerite (p. 424)........	3·47	6–7
Andesine (p. 379).......	2·68–2·69	6–6·5	Chloritoid? (p. 471).....	3·52–3·57	6·5
Labradorite (p. 379)....	2·70–2·72	6–6·5	Roselite (p. 507).........	3·5–3·6	3·5
Anorthite (p. 380)......	2·74–2·76	6–6·5	**Cyanite** (p 434)	3·56–3·67	5–7·25
Monetite (p. 507)........	2·75	3·5	Brandtite (p. 507)........	3·67	5–5·5
Inesite (p 452).........	3 03	6	Ænigmatite (p. 405)....	3·85	
Amblygonite (p. 503)....	3·01–3·09	6	Walpurgite? (p. 515)....	5·76	3·5

II. CRYSTALLINE HABIT.

I. ISOMETRIC SYSTEM.

In the following lists some species are enumerated whose crystalline habit is often so marked as to be a distinctive character.

Cubes.—Metallic Luster: Galena; Pyrite.

Unmetallic Luster: Fluorite; Cuprite; Cerargyrite; Halite; Sylvite; Boracite; Pharmacosiderite. Also Percylite; Cerargyrite; Perovskite.

Cube-like forms occur with the following: Apophyllite (tetragonal); Cryolite (monoclinic). Also with the rhombohedral species: Chabazite: Alunite; Calcite; rarely Quartz and Hematite.

Octahedrons.—Metallic and Submetallic Luster: Magnetite; Franklinite; Chromite; Uraninite. Also sometimes, Galena; Pyrite; Linnæite; Dysanalyte.

Unmetallic Luster: Spinel (incl. Hercynite and Gahnite); Cuprite; Diamond; Pyrochlore and Microlite; Ralstonite; Periclase; Alum.

Forms somewhat resembling regular octahedrons occur with some tetragonal species, as Braunite; Hausmannite; Chalcopyrite; Zircon, etc.; also with some rhombohedral species, as Dolomite.

Dodecahedrons.—Metallic Luster: Magnetite; Amalgam.

Unmetallic Luster: Garnet; Cuprite; Sodalite.

Trapezohedrons.—Unmetallic Luster: Garnet; Leucite; Analcite.

Pyritohedrons.—Metallic Luster: Pyrite; Cobaltite. Also Gersdorffite; Hauerite (submetallic).

Tetrahedrons.—Metallic Luster: Tetrahedrite.

Unmetallic Luster: Sphalerite; Boracite; Helvite; Eulytite; Diamond.

The tetragonal sphenoids of Chalcopyrite may resemble tetrahedrons.

II. TETRAGONAL SYSTEM.

Square Pyramids.—Submetallic Luster: Braunite; Hausmannite.

Unmetallic Luster: Zircon; Wulfenite; Vesuvianite; Octahedrite; Xenotime.

Square Prisms.—Unmetallic Luster: Zircon; Vesuvianite; Scapolites; Apophyllite; Phosgenite.

Square tabular crystals occur with Apophyllite; Wulfenite; Torbernite.

Prisms nearly square are noted with a number of orthorhombic species, e.g., Topaz; Andalusite; Danburite.

III. HEXAGONAL SERIES.

Hexagonal Prisms.—Unmetallic Luster: Beryl; Apatite; Pyromorphite; Vanadinite; Mimetite (usually indistinct rounded forms. Also Nephelite; Milarite; Tysonite, and others.

Hexagonal prisms are also common with the *rhombohedral species*: Quartz; Calcite; Tourmaline; Willemite; Phenacite; Dioptase, etc. Again, with the Micas, etc. Numerous rare species could be included here.

Many *orthorhombic* (or *monoclinic*) species having a prismatic angle of about 60° (and 120°) simulate this form both in simple crystals and still more as the result of twinning Thus, Aragonite; Strontianite; Leadhillite; Iolite. It is also to be noted that the *isometric* dodecahedron, e.g., of Garnet, has often the form of a hexagonal pyramid with trihedral terminations (cf. Fig. 442. p. 134).

Tabular hexagonal prisms are noted with various species. Thus, Metallic Luster: Hematite; Ilmenite; Pyrrhotite. Unmetallic Luster: Tridymite.

Hexagonal Pyramids.—Apatite: Corundum (rhombohedral); Quartz (rhombohedral-trapezohedral); Hanksite.

This form is often simulated by various *orthorhombic* species, in part as the result of twinning. For example, metallic luster: Chalcocite; Stephanite; Polybasite; Jordanite, etc Also Brookite (Fig. 301. p. 94)

Unmetallic Luster: Witherite; Bromlite; Cerussite; Iolite.

Trigonal Prism.—Tourmaline.

Rhombohedrons.—Angle 75° (and 105°) : Calcite; Dolomite; Siderite; Rhodochrosite. Angle not far from 90°: Chabazite; Alunite.

Scalenohedrons.—Calcite and allied Carbonates; Proustite.

IV. ORTHORHOMBIC, MONOCLINIC AND TRICLINIC SYSTEMS.

Prismatic Crystals.—METALLIC LUSTER : Stibnite; Arsenopyrite; Bournonite; Manganite; Göthite, etc.

UNMETALLIC LUSTER : (*orthorhombic*) Topaz; Staurolite; Andalusite; Barite; Celestite; Danburite. Also (*monoclinic*) Pyroxene; Amphibole; Orthoclase, and many others.

Epidote crystals are often prismatic in aspect (Fig. 850, p. 438).

Tabular Crystals.—Barite; Cerussite; Calamine; Diaspore; Wollastonite.

Acicular Crystals.—METALLIC LUSTER : Stibnite; Bismuthinite; Millerite; Jamesonite; Aikinite, and other species.

UNMETALLIC LUSTER : Pectolite; Natrolite; Scolecite; Thomsonite, and other Zeolites. Also Aragonite; Strontianite; less often Calcite. Also many other species.

Twin Crystals.—The habit of the twins occurring with many species is very characteristic. Reference is made to pp. 118 to 130 and the accompanying figures for a presentation of this subject.

III. STRUCTURE OF MASSIVE MINERALS.

Fibrous.—*Fibers separable:* Asbestus (amphibole); also the similar asbestiform variety of serpentine (chrysotile); Crocidolite (color blue).

Fibers not separable, chiefly straight : Calcite; Gypsum. Also Aragonite; Barite; Celestite; Anhydrite; Brucite; Enstatite; Wollastonite; Dufrenite; Vivianite. See also *Columnar* below.

Fibrous-Radiated.—Wavellite; Thomsonite; Natrolite; Stilbite, and other Zeolites; Göthite; Malachite.

Columnar.—METALLIC LUSTER : Stibnite; Hematite; Jamesonite; Zinkenite, etc.

UNMETALLIC LUSTER : Limonite; Göthite; Aragonite; Amphibole (tremolite, actinolite, etc.); Epidote; Zoisite; Tourmaline; Sillimanite; Natrolite and other Zeolites; Strontianite; Witherite; Topaz.

Cyanite has often a *bladed* structure.

Fibrous and columnar varieties pass into one another.

Lamellar-Stellate.—Gypsum; Pyrophyllite.

Foliated.—METALLIC LUSTER : Graphite; Molybdenite; Tetradymite; Sternbergite; Nagyagite.

UNMETALLIC LUSTER : Talc; Orpiment; Gypsum; Pyrophyllite; Serpentine; Gypsum.

Micaceous.—The Micas, p. 463; also the Brittle Micas, p. 470, and the Chlorites, p. 472. Also Brucite; Orpiment; Talc; Torbernite; Autunite.

Granular.—METALLIC LUSTER : Galena; Hematite. Many sulphides, sulpharsenites, etc., have varieties which are fine-granular to compact and impalpable.

UNMETALLIC LUSTER : Pyroxene (coccolite); Garnet; Calcite; Barite, etc.

Botryoidal, Mammillary, Reniform, etc.—METALLIC LUSTER : Hematite; Arsenic; Allemontite.

UNMETALLIC LUSTER : Malachite; Prehnite; Calamine; Smithsonite; Chalcedony; Hyalite; Sphalerite, etc.

Stalactitic.—METALLIC LUSTER : Limonite; Psilomelane; Marcasite.

UNMETALLIC LUSTER : Calcite; Aragonite; Gibbsite; Chalcedony.

IV. PHYSICAL CHARACTERS.

I. CLEAVAGE.

Cubic.—METALLIC LUSTER : Galena.

UNMETALLIC LUSTER : Halite; Sylvite. The cleavage of Anhydrite (also of Cryolite) simulates this. Cf. also Corundum, p. 383.

Octahedral.—Fluorite; Diamond. Magnetite (also Franklinite) has often distinct octahedral parting.

Dodecahedral.—Sphalerite.

Rhombohedral.—Calcite and other species of the same group, pp. 354–360.

Square Prismatic (90°).—Scapolite; Rutile; Xenotime.

Prismatic.—Barite; Celestite; Amphibole (54° and 126°), etc.

Basal.—Metallic Luster: Graphite; Molybdenite.

Unmetallic Luster: Apophyllite; Topaz; Talc; the Micas and Chlorites; Chalcophyllite, etc. Pyroxene often shows marked basal parting.

Pinacoidal.—Metallic Luster: Stibnite.

Unmetallic Luster: Gypsum; Orpiment; Euclase; Diaspore, etc.

II. HARDNESS.

1. **Soft Minerals.**—The following minerals are conspicuously *Soft*, that is, H = 2 or less; they hence have a *greasy* feel. (See further the Tables, pp. 557 to 563.)

Metallic Luster: Graphite; Molybdenite; Tetradymite; Sternbergite; Argentite; Nagyagite; some of the Native Metals (Lead, etc.).

Unmetallic Luster: Talc; Pyrophyllite; Brucite; Tyrolite; Orpiment; Cerargyrite; Cinnabar; Sulphur; Gypsum.

Also Calomel, Arsenolite, and many hydrous sulphates, phosphates, etc.

2. **Hard Minerals.**—Minerals whose hardness is equal to or greater than 7 (Quartz = 7).

The following minerals are here included:

Luster Unmetallic.

Quartz (p. 324)	7	Hambergite (p. 518)	7·5
Tridymite (p. 328)	7	Zircon (p. 428)	7·5
Barylite (p. 408)	7	Andalusite (p. 432)	7·5
Dumortierite (p. 449)	7	Beryl (p. 405)	7.5–8
Danburite (p. 430)	7–7·25	Lawsonite (p. 447)	7·5–8
Boracite (p. 518)	7	Phenacite (p. 423)	7·5–8
Zunyite (p. 415)	7	Gahnite (p. 339)	7·5–8
Cyanite (p. 434)	5–7·25	Hercynite (p. 339)	7·5–8
Tourmaline (p. 447)	7–7·5	Spinel (p. 338)	8
Garnet (p. 415)	6·5–7·5	Topaz (p. 431)	8
Iolite (p. 407)	7–7·5	Rhodizite (p. 518)	8
Staurolite (p. 450)	7–7·5	Chrysoberyl (p. 342)	8·5
Schorlomite (p. 419)	7–7·5	Corundum (p. 333)	9
Sapphirine (p. 451)	7·5	Diamond (p. 271)	10
Euclase (p. 436)	7·5		

The following minerals have hardness equal to 6 to 7, or 6·5—7.

Luster Metallic: Iridosmine (p. 280); Iridium (p. 280); Sperrylite (p. 302).

Luster Unmetallic: Ardennite (p. 445); Axinite (p. 441); Betrandite (p. 446); Cassiterite (p. 344); Chrysolite (p. 420); Diaspore (p. 348); Elpidite (p. 407); Epidote (p. 438); Forsterite (p. 422); Gadolinite (p. 436); Jadeite (p. 393); Partschinite (p. 419); Sillimanite (p. 433); Spodumene (p. 393); Trimerite (p. 424).

III. SPECIFIC GRAVITY.

Attention is called to the remarks in Art. 280 (p. 158), on the relation of specific gravity to chemical composition. Also to the statements in Art. 281 as to the *average* specific gravity among minerals of metallic and unmetallic luster respectively. The species in each of the separate lists of Table I. of minerals classified with reference to crystallization are arranged according to ascending *specific gravities*. Hence the lists give at a glance minerals distinguished by both low and high density.

IV. LUSTER. (See Art. 338, p. 188.)

Metallic.—Native metals; most Sulphides; some Oxides, those containing iron, manganese, lead, etc.

Submetallic.—Here belong chiefly certain iron compounds, as Ilmenite; Ilvaite; Columbite; Tantalite (and allied species); Wolframite, etc. Also Uraninite, etc.

Adamantine.—(*a*) Some *hard* minerals: Diamond; Corundum; Cassiterite; Zircon; Rutile. (*b*) Many compounds of lead, also of silver, copper, mercury. Thus, Cerussite, Anglesite, Phosgenite, etc.; Cerargyrite; Cuprite; some Cinnabar, etc. (*c*) Also certain varieties of Sphalerite, Titanite and Octahedrite.

Metallic-Adamantine —Pyrargyrite; some varieties of the following: Cuprite, Cerussite, Octahedrite, Rutile.

Resinous or Waxy.—Sphalerite; Elæolite; many Phosphates.

Vitreous.—Quartz and many Silicates, as Garnet, Beryl.

Pearly.—The foliated species: Talc, Brucite, Pyrophyllite. Also (on cleavage surfaces) conspicuously the following: Apophyllite, Stilbite, Heulandite. Also, less prominent: Barite; Celestite; some Feldspar, and others.

Silky.—Some fibrous minerals, as Gypsum, Calcite; also Asbestus.

V. COLOR.

The following lists may be of some use in the way of suggestion. It is to be noted, however, that especially in the case of metallic minerals a slight surface change may alter the effect of color. Further, among minerals of unmetallic luster particularly, no sharp line can be drawn between colors slightly different, and many variations of shade occur in the case of a single species. For these reasons no lists, unless inconveniently extended, could make any claim to completeness.

(*a*) METALLIC LUSTER.

Silver-white, Tin-white.—Native silver; Native Antimony, Arsenic and Tellurium; Amalgam; Arsenopyrite and Löllingite; several sulphides, arsenides, etc., of cobalt or nickel, as Cobaltite (reddish); some Tellurides. No sharp line can be drawn between these and the following group.

Steel-gray.—Platinum; Manganite; Chalcocite; Sylvanite; Bournonite.

Blue-gray.—Molybdenite.

Lead-gray.—Many sulphides, as Galena (bluish); Stibnite; many Sulpharsenites, etc., as Jamesonite, Dufrenoysite, etc.

Iron-black.—Graphite; Tetrahedrite; Polybasite; Stephanite; Enargite; Pyrolusite; Magnetite; Hematite; Franklinite.

Black (with submetallic luster).—Ilmenite; Limonite; Columbite; Tantalite, etc.; Wolframite; Ilvaite; Uraninite, etc. The following are usually brownish black: Braunite; Hausmannite.

Copper-red.—Native copper.

Bronze-red.—Bornite (quickly tarnished); Niccolite.

Bronze-yellow.—Pyrrhotite; Pentlandite; Breithauptite.

Brass-yellow.—Chalcopyrite; Millerite (bronze.) Pale brass-yellow: Pyrite; Marcasite (whiter than Pyrite).

Gold-yellow.—Native gold.

Streak.—The following minerals of metallic luster are notable for the color of their *streak:*

Cochineal-red: Pyrargyrite.
Cherry-red: Miargyrite.
Dull Red: Hematite (also Cuprite).
Scarlet: Cinnabar (usually unmetallic).

Dark Brown: Manganite; Franklinite; Chromite.
Yellow: Limonite.

Tarnish.—The following are conspicuous for their bright or variegated tarnish: Bornite; Chalcopyrite; Tetrahedrite; some Limonite.

(*b*) Unmetallic Luster.

Colorless.—In Crystals: Quartz; Calcite; Aragonite; Gypsum; Cerussite; Anglesite; Albite; Barite; Adularia; Topaz; Apophyllite; Natrolite and other Zeolites; Celestite; Diaspore; Nephelite; Meionite; Calamine; Cryolite; Phenacite, etc.
Massive: Quartz; Calcite; Gypsum; Hyalite (botryoidal).

White.—Crystals: Amphibole (tremolite); Pyroxene (diopside, usually greenish).
Massive: Calcite; Milky Quartz; Feldspars, especially Albite; Barite; Cerussite; Scapolite; Talc; Meerschaum; Magnesite; Kaolinite; Amblygonite, etc.

Blue.—Blackish Blue: Azurite; Crocidolite.
Indigo-blue: Indicolite (Tourmaline); Vivianite.
Azure-blue: Lazulite; Azurite; Lapis Lazuli; Turquois.
Prussian-blue: Sapphire; Cyanite; Iolite; Azurite; Chalcanthite and many copper compounds.
Sky-blue, Mountain-blue: Beryl; Celestite.
Violet-blue: Amethyst; Fluorite.
Greenish Blue: Amazon-stone; Chrysocolla; Calamine; Smithsonite; some Turquois; Beryl.

Green.—Blackish Green: Epidote; Serpentine; Pyroxene; Amphibole.
Emerald-green: Beryl (Emerald); Malachite; Dioptase; Atacamite; and many other copper compounds; Spodumene (hiddenite); Pyroxene (rare); Gahnite; Jadeite and Jade.
Bluish Green: Beryl; Apatite; Fluorite; Amazon-stone; Prehnite; Calamine; Smithsonite; Chrysocolla; Chlorite; some Turquois.
Mountain green: Beryl (aquamarine); Euclase.
Apple-green: Talc; Garnet; Chrysoprase; Willemite; Garnierite; Pyrophyllite; some Muscovite; Jadeite and Jade; Pyrophyllite.
Pistachio-green: Epidote.
Grass-green: Pyromorphite; Wavellite; Variscite; Chrysoberyl.
Grayish Green: Amphibole and Pyroxene, many common kinds; Jasper; Jade.
Yellow-green to Olive-green: Beryl; Apatite; Chrysoberyl; Chrysolite (olive-green); Chlorite; Serpentine; Titanite; Datolite; Olivenite; Vesuvianite.

Yellow.—Sulphur-yellow: Sulphur; some Vesuvianite.
Orange-yellow: Orpiment; Wulfenite; Mimetite.
Straw yellow, also Wine-yellow, Wax-yellow: Topaz; Sulphur; Fluorite; Cancrinite; Wulfenite; Vanadinite; Willemite; Calcite; Barite; Chrysolite; Chondrodite; Titanite; Datolite, etc.
Brownish Yellow: Much Sphalerite; Siderite; Göthite.
Ocher yellow: Göthite; Yellow ocher (limonite).

Red.—Ruby-red: Ruby (corundum); Ruby spinel; much Garnet; Proustite; Vanadinite; Sphalerite; Chondrodite.
Cochineal-red: Cuprite; Cinnabar.
Hyacinth-red.—Zircon.
Orange red: Zincite.
Orange-red to aurora-red: Realgar; Wulfenite.
Crimson-red: Tourmaline (rubellite); Spinel, Fluorite.
Scarlet-red: Cinnabar.
Brick-red: Some Hematite (red ocher).
Rose-red to Pink: Rose quartz; Rhodonite; Rhodochrosite; Erythrite; some Scapolite. Apophyllite and Zoisite; Eudialyte; Petalite; Margarite.
Peach-blossom Red to Lilac: Lepidolite; Rubellite.
Flesh-red: Some Orthoclase; Willemite (the variety troostite); some Chabazite; Stilbite and Heulandite; Apatite; rarely Calcite; Polyhalite.
Brownish Red: Jasper; Limonite; Garnet; Sphalerite; Siderite; Rutile.

Brown.—REDDISH BROWN : Some Garnet ; some Sphalerite ; Staurolite ; Cassiterite ; Rutile.

CLOVE BROWN : Axinite ; Zircon ; Pyromorphite.

YELLOWISH BROWN : Siderite and related carbonates ; Sphalerite ; Jasper ; Limonite ; Göthite ; Tourmaline ; Vesuvianite ; Chondrodite ; Staurolite.

BLACKISH BROWN : Titanite ; some Siderite ; Sphalerite.

SMOKY BROWN : Quartz.

Black : Tourmaline ; black Garnet (melanite) ; some Mica (especially biotite) ; also some Amphibole, Pyroxene and Epidote (these are mostly greenish or brownish black) ; further, some Sphalerite and some kinds of Quartz (varying from smoky brown to black) ; also Allanite ; Samarskite. Some black minerals with submetallic luster are mentioned on p. 483.

Streak.—The *streak* is to be noted in the case of some minerals with unmetallic luster. By far the majority have, even when deeply colored in the mass (e.g. Tourmaline), a streak differing but little from white. The following may be mentioned:

ORANGE-YELLOW : Zincite, Crocoite.

COCHINEAL-RED : Pyrargyrite and Proustite.

SCARLET RED : Cinnabar.

BROWNISH RED : Cuprite ; Hematite.

BROWN : Limonite.

The streak of the various copper, green and blue minerals, as Malachite, Azurite, etc., is about the same as the color of the mineral itself, though often a little paler.

GENERAL INDEX.

A

Abbreviations, 4
Absorption of light, 171
    biaxial crystals, 218
    uniaxial crystals, 201
Acicular crystals, 142
Acid salts, 247
Acids, 246
Actino-electricity, 235
Adamantine luster, 188
Aggregate polarization, 228
Aggregates, crystalline, 142
    optical properties, 228
Airy's spirals, 203
Albite law (twinning), 131, 375
Alkalies, test for, 258
Alkaline taste, 238
Alliaceous odor, 238
Aluminium (aluminum), test for, 258, 264
Amalgam, 186, 187
Amorphous structure, 6, 143
Amplitude of vibration, 162
Amygdaloidal structure, 143
Analyzer, 177
Analysis, blowpipe, 256
    chemical, 252
    microchemical, 252
Angle, critical, 169
    of extinction, 211
        polarization, 175
Angles, measurement of, 112
    of dihexagonal prisms, 88
        ditetragonal prisms, 64
        isometric forms, 42, 46, 49
Anisometric crystals, 192
Anisotropic crystals, 192
Anomalies, optical, 228
Antimony, tests for, 259, 260, 261, 264
Apatite type, 71
Arborescent structure, see Dendritic, 143
Argillaceous odor, 238
Arsenic, tests for, 259, 260, 261, 264
Artificial minerals, 1, 252
Asterism, 190, 470
Astringent taste, 238
Asymmetric group, 109
Atom, 239
Atomic weight, 240
Axes, crystallographic, 13, 22
Axes, ether, 208
    of elasticity, 208
    optic, 207, 215
        dispersion of, 210, 220
Axial angle, optic, 209, 215
        measurement of, 215
    figure, 199, 214
    planes of symmetry, 14
    ratio, 22

B

Barium, test for, 259, 264
Basal plane, 53, 67, 90, 100, 107
    projections, 26
        drawing of, 553
Base, 53, 67, 90, 100, 107
Bases, chemical, 246
Basic salts, 247
Baveno twins, 129, 371
Belonite, 140
Bertrand ocular, 211
Beryl type, 66
Berylloid, 69
Bevel, Bevelment, 37
Biaxial crystals, 192, 203
        examination of, 210
Binary symmetry, 9
Birefringence, 172, 197, 198, 512
        determination of, 212
Bisectrices, 208
    dispersion of, 210, 222
Bisectrix, acute, 208
    negative, 217
    obtuse, 208
    positive, 217
Bismuth, test for, 261, 264
Bitter taste, 238
Bituminous odor, 238
Bivalent element, 244
Bladed structure, 142
Blebby bead, 258
Blowpipe, 256
Borax, use of, 263
Boron, test for, 259, 264
Botryoidal structure, 143
Brachy-axis, 89, 106
Brachydome, 91, 107
Brachypinacoid, 90, 107

Brachyprism, [illegible], 107
Brachypyramid, 92, 107
[illegible], 257, 258
[illegible], 173
[illegible], 154
[illegible], 256
[illegible] blowpipe, 256

C

Cadmium, test for, 262, 265
Calcite type, 74
Calcium, test for, 258, 265
Calculation of angles, 32, 52, 62, 54, 56,
104, 140
chemical formula, 249
Capillary crystals, 143
Carbonates, test for, 265
Carlsbad twin, 128, 129
Chalcopyrite type, 62
Change of colors, 179
Charcoal, use of, 255, 256
Chemical compound, 245
composition and optical characters, 235
elements, 236
formula, 249
mineralogy, 236
reaction, 245
symbol, 240
tests, 254, 264
Chlorides, test for, 265
Chlorine, test for, 255, 259
Chondrodite, 421
Chromium, tests for, 263, 265
Circular polarization, 175, 202
imitated by mica sections, 227
Classification of minerals, 376
Cleavage, 146
basal, 147
cubic, 147
dodecahedral, 147
octahedral, 147
prismatic, 147
rhombohedral, 147
Clino-axis, 95
Clinodome, 101
Clinohedral group, 104
Clinopinacoid, 100
Clinoprism, 100
Clinopyramid, 101
Closed form, 25
Closed tube, 259
Cobalt, test for, 262, 265
nitrate, use of, 258
Cohesion, 146
Color, 164, 186, 187
complementary, 164, 178
Columnar structure, 142
Combining weight, 243
Complementary colors, 164, 178
Composition-plane, 119
Concentric structure, 142
Conchoidal fracture, 152
Conductivity for electricity, 234
heat, 232
Conical refraction, 207
Conoscope, 197
Constancy of crystal angles, 7
Contact goniometer, 118
Contact-twin, 120
Cooling tests, 258
Copper, tests for, 258, 262, 263, 265
Copper chloride, test for, 259
Coralloidal structure, 143
Corrosion forms, 132
Cotangent relation, 31
Critical angle, 169
Crossed dispersion, 223
Crypto-crystalline, 6, 143
Crystal, definition, 5
distorted, 11, 138
twin, 119
Crystallites, 144
Crystalline aggregate, 6, 142
structure, 6
Crystallization, systems of, 13
Crystallogeny, 5
Crystallography, 5
Cube, 34
Cuprite type, 39
Curved crystals and faces, 137

D

Decrepitation, 256, 259
Deltoid dodecahedron, 42
Dendrites, 143
Dendritic structure, 143
Density, 156
Description of species, 369
Determination of minerals, 367
Diagonal prism, 67
pyramid, 69
Diamagnetic minerals, 237
Diamagnetism, 237
Diametral prism, 54, 90, 100, 108
pyramid, 55
Diaphaneity, 186
Diathermancy, 233
Dibasic acid, 246
Dichroic crystals, 202
Dichroism, 187, 201
Dichroscope, 202
Diffraction, 171
Dihexagonal prism, 67
pyramid, 69
Dimorphism, 251
Dimorphous compound, 251
Diploid, 44
Dispersion, 170
of bisectrices, 210, 222
crossed, 223
horizontal, 223
inclined, 222
of optic axes, 210, 220

Distorted crystals, 11, 138
Ditetragonal prism, 55
    pyramid, 57
Ditrigonal prism, 83
Divergent structure, 142
Dodecahedron, 34
    deltoid, 48
    dyakis, 44
    pentagonal, 43
        tetrahedral, 51
    rhombic, 34
Domes, 26, 91, 100, 101, 107
Double refraction, 172
Drawing of crystals, 547
Drusy, 143
Dyakis-dodecahedron, 44

E

Earthy fracture, 152
Effervescence, 254
Elasticity, 154
    axes of light-, 208
Elastic minerals, 154
Electricity, 234
Electro-negative elements, 242
    positive elements, 242
Elements, angular, 96, 104, 110
    axial, 96, 104, 110
    chemical, 239, 240
    equivalence of, 105
Elliptically polarized light, 178
Elongation, negative or positive, 213
Enantiomorphous forms, 50, 82
Epoptic figures, 219
Etching, 149
    figures, 149
Ether, luminiferous, 160
    axes, 203, 208, 219, 220
Even fracture, 152
Exfoliation, 258
Expansion by heat, 232
Extinction, 177, 210
    oblique, 211
    parallel, 211
Extinction-angle, 211
Extraordinary ray, 194, 205

F

Federow mica-wedge, 213
Feel, 238
Fetid odor, 238
Fibrous structure, 142
Filiform, 143
First order prisms, 53, 67
    pyramids, 54, 68
Flame coloration, 259
    oxidizing, 257
    reducing, 257
Flexible, 154
Fluorescence, 190
Fluorides, fluorine, test for, 260, 265
Fluxes, 262
Foliated structure, 142
Forceps, 257, 258
Form, 25
Formula, chemical, 240, 248
        calculation of, 249
Formulas for spherical triangles, 32
Fracture, 151
Fundamental form, 25
Fusibility, 232, 258
    scale of, 258

G

Galena type, 33
Gladstone law, 169
Glass, optical characters of, 192, 228
Glass tubes, 257; use of, 259
Gliding planes, 147
Glimmering luster, 189
Glistening luster, 189
Globular structure, 143
Globulites, 140
Glowing, 258, 259
Goniometer, contact or hand, 112
    horizontal, 115
    reflecting, 112, 115
    theodolite, 117
Granular structure, 142
Greasy luster, 189
Grouping, molecular, 21
    parallel, 131, 132
Gyroidal forms, 50

H

Habit, crystal, 8
Hackly fracture, 152
Hand goniometer, 112
Hard minerals, 153
Hardness, 152
Heat, 231
    effect on optical properties, 224
Heavy solutions, 158
Hemihedral forms, 17
Hemimorphic forms, 18
    groups, 59, 71, 95, 103
Hexagonal prisms, 67
    pyramids, 68
    symmetry, 10
    system, 65, 15
    trapezohedron, 74
Hexakisoctahedron, 39
Hexakistetrahedron, 49
Hexoctahedron, 39
Holohedral forms, 17
Horizontal dispersion, 223
    prisms, 92
    projections, 26
Horse-radish odor, 238
Houppes, 219
Hour-glass structure, 390
Hydroxides, 246

I

Icosahedron, 44, 47
Icositetrahedron, 39
Idiophanous crystals, 219
Impalpable structure, 142
Indicatrix, 196, 204
Indices, crystallographic, 24
refractive, 168
Incidence, angle of, 164
Inclined dispersion, 223
hemihedrons, 47
Inclusions, 139
Inelastic minerals, 154
Insoluble minerals, 255
Interference of light, 173, 177
colors, 173, 177
uniaxial crystals, 198
biaxial, 214
figures, uniaxial, 199
Intumescence, 258
Iodyrite type, 71
Iridescence, 189
Iron, test for, 263, 265
Iron cross, 124
Isodiametric crystals, 192
Isodimorphism, 251
Isometric crystals, optical properties, 193
system, 38, 14
Isomorphous group, 250
mixtures, 251
Isomorphism, 250

J

Jolly balance, 157

K

Klein solution, 158

L

Lamellar polarization, 229
structure, 142
Lamp for blowpipe, 256
Law of frational indices, 25
Lead, test for, 261, 262, 265
Left-handed crystal, 83, 325
polarization, 179
Light, nature of, 160
Light-ray, 163
Light-waves, 162
Light-velocity, relation to refractive index, 168
Lithium, test for, 259, 266
Luster, 188

M

Macro-axis, 89, 106
Macrodome, 91, 107
Macropinacoid, 90, 107
Macroprism, 91, 107
Macropyramid, 92, 107
Magnesium, test for, 258, 266
Magnetic minerals, 237
Magnetism, 237
Magnets, natural, 237
Malleable minerals, 154
Mammillary structure, 143
Manganese, test for, 263, 266
Margarites, 140
Manebach twin, 129, 371
Mean-line, 208
first, 208
second, 208
Mercury, test for, 260, 266
sulphide, test for, 260
Metagenic twins, 121
Metallic-adamantine luster, 189
Metallic luster, 188
Metallic pearly luster, 189
Metals, 241
Mica sections superposed, 227
Mica-wedge, 213
Micaceous structure, 142
Microcosmic salt, v. Salt of phosphorus, 263
Microlites, 140
Microsclerometer, 153
Miller's symbols, 24
system, 124, 88
Mimetic crystals, 12
Mineral, artificial, 1, 252
definition of, 1
Mineral kingdom, 1
Mineralogy, science of, 1, 2
Models of crystals, 17
Molecular networks, 18
structure, 5, 145
weight, 244
Molecule, 240, 5
Molybdenum, tests for, 260, 261, 263, 266
Monad, 244
Monobasic acid, 246
Monoclinic crystals, 98
optical characters, 220
examination of, 220
system, 98; 16
Mossy structure, 143

N

Natural magnets, 237
Naumann's symbols, 24
Negative crystal, 209
biaxial, 149
uniaxial, 194, 197, 201
element, 242
elongation, 213
Nephelite type, 73
Neutral salt, 247
Network, molecular, 18
Newton's rings, 174
Nickel, test for, 263, 266
Nicol prism, 176
Niobium, test for, 266
Nitrates, test for, 266
Nodular structure, 143
Non-metals, 241

Normal angles, 28
  groups, 14, 33, 53, 66, 89, 99, 107
  salt, 247
Nugget, gold, 277

O

Octahedron, 34
  square, 55, 56
Octant, 23
Ocular, Bertrand, 211
Odor, 238
Opalescence, 189
Opaque, 186
Open tube, 260
  form, 25
Optic axes, 204, 207
  axis, 194
Optical anomalies, 228
  characters of crystalline aggregates, 228
    twin crystals, 226
  effect of heat upon, 224
    pressure on, 228
  relation to chemical composition, 225
Order, prisms and pyramids of first and second, 53, 54,66 , 67
    third, 71
  rhombohedrons of second and third, 80, 81
Ordinary ray, 194, 205
Ortho-axis, 98
Orthodome, 100
Orthopinacoid, 100
Orthoprism, 100
Orthopyramid, 101
Orthorhombic crystals, 89
    optical examination, 229
  system, 89 ; 16
Oscillatory combination, 136
Oxides, 245
Oxidizing flame, 257
Oxygen ratio, 249

P

Paragenic twins, 121
Parallel extinction, 211
  grouping, 131, 132
  hemihedrons, 43
Paramagnetic minerals, 237
Paramagnetism, 237
Parameter, 23
Paramorph, 253
Paramorphism, 253
Parting, 148
Pearly luster, 189
Penetration-twin, 120
Pentagonal dodecahedron, 43
    tetrahedral, 52
  icositetrahedron, 50
Pentavalent element, 244
Percussion figure, 149
Pericline law (twinning), 131, 375
Periodic law, 242
Phanero-crystalline, 142
Phenacite type, 80
Phosphates, test for, 255, 259
Phosphorescence, 190, 259
Phosphoric acid, test for, 255, 259, 266
Photo-electricity, 235
Physical characters, 145
Piezo-electricity, 235
Pinacoids, 20
Plagihedral group, 50
Plane-polarized light, 174
Plane of polarization, 174
Platinum wire, 257, 262
Play of colors, 189
Pleochroic halos, 219
Pleochroism, 187
Pleomorphism, 251
Point system, 19
Polariscope, 177, 181
Polarization, 174
Polarization-brushes, 219
  -microscope, 183
Polarized light, 174
Polarizer, 177
Polysynthetic twinning, 375
Positive crystal, biaxial, 209, 217
    uniaxial, 194, 197, 201
  element, 242
  elongation, 213
Potassium, test for, 259, 266
Pressure, effect on optical characters, 228
  figures, 149
Primary optic axes, 207
Principal axis or plane of symmetry, 14
  section, 194
Prisms, 26
  ditrigonal, 83
  hexagonal, 66, 67, 71
  horizontal, 92
  rhombic, 90
  tetragonal, 53
  third order, 57, 71
  trigonal, 83
Projection, basal, 26, 553
  horizontal, 26, 553
  spherical, 27, 554
  drawing of, 554
Pseudo-hexagonal crystals, 12, 127, 354
  -isometric crystals, 229
Pseudomorph, 144, 252
Pseudomorphism, 252
Pseudosymmetry, 12, 41, 122, 133, 226
Pycnometer, 157
Pyramid, diametral, 55
  ditrigonal, 74
  hexagonal, 68, 69, 71
  rhombic, 92
  square, 55, 56, 59
  third order, 59, 71
  trigonal, 83

Pyramid, unit, 56
Pyramidal group, 59, 71
    hemihedrism, 60
    -hemimorphic group, 61, 73
Pyrite type, 43
Pyritohedral group, 43
    symmetry, 43
Pyritohedron, 43
Pyro-electricity, 234
Pyrognostics, 264

Q

Quarter-undulation mica plate,
Quartz-wedge, 212

R

Radiated structure, 142
Radical, chemical, 245
Rational indices, law of, 25
Reaction, chemical, 245
Reagents, chemical, 254
Reducing flame, 257
Reduction of metals, 261
Reflecting goniometer 12, 115
Reflection of light, 164
    angle of, 164
Reflectometer, 180
Refraction, 166 -refringence
    double, 172
        strength of, 172
    index v. Refractive index
Refractive equivalent, 169
    index, 166, 168
        determination of, 170, 180, 200, 213
        relation to light velocity, 168
    indices, principal, 168, 203
Refractometer, 180
Relief, high or low, 170
Reniform structure, 143
Resinous luster, 188
Reticulated structure, 142, 143
Rhombic prism, 90
    pyramid, 92
    section, 375
    sphenoid, 96
Rhombohedral system, 16, 74
    of Miller, 88
Rhombohedral-hemimorphic group, 79
Rhombohedron 75, 80
Right-handed crystal, 83, 324
    polarization, 178
Roasting, 261
Röntgen rays, 235

S

Saline taste, 238
Salt of phosphorus, 263
Salts, 247
Saturation, 245
Scale of fusibility, 258
Scale of hardness, 152
Scalenohedron, 77
    tetragonal, 62
Scheelite type, 59
Schiller, 190
Schillerization, 190
Sclerometer, 152
Second order prism, 67
    pyramid, 68
    rhombohedron, 80
Secondary optic axes, 207
    twinning, 122, 148
Sectant, 23
Sectile, 154
Selenite-plate, 201, 213
Selenium, tests for, 260, 261, 266
Semi-metals, 24
Semi-transparent, 186
Separable, 142
Shining luster, 189
Silica, test for, 266
Silky luster, 189
Silver, test for, 255, 261, 262, 266
Soda, use of, 261, 262
Sodium, test for, 259, 266
Soft minerals, 152
Solubility in acids, 254
Solution-planes, 149
Sonstadt solution 158
Sound waves, 161
Specific gravity, 156
    balance, 156, 157,
    heat, 233
    refractive power, 169
Spectroscope, 170
Spelter, 233
Sphenoid, 62; rhombic, 96
Sphenoidal group, 61, 96
Spherical projections, 27
    construction, 554
    triangles, formulas, 32
Spherulites, 228, 372
Splendent luster, 189
Splintery fracture, 152
Square prisms, 54, 59
    pyramids, 55, 56, 59
Stalactitic structure, 143
Stauroscope, 181, 221
Stellated structure, 142
Streak, 187
Strength of double refraction, 172, 197, 198, 212
Striations, 136
Strike-figure v. Percussion-figure, 149
Strontium, test for, 259, 266
Sublimate, 260
Subtranslucent, 186
Subtransparent, 186
Subvitreous, 188
Sulphates, test for, 262
Sulphides, 246, 266
Sulpho-salts, 248
Sulphur, test for, 255, 260, 266
Sulphurous odor, 238

Swelling up, 258
Symbol, chemical, 240
  crystallographic, 23
Symmetry, 8
  axis of, 9
  center of, 10
  exhibited by spherical projection, 29
  groups of, 13
  planes of, 9
Synthesis, mineral, 252
System, hexagonal, 65
  isometric, 33
  monoclinic, 98
  orthorhombic, 89
  rhombohedral, 74
  tetragonal, 53
  triclinic, 106
Systems of crystallization, 13

T

Tangent relation, 31
Tarnish, 190
Taste, 238
Tellurium, tests for, 260, 261, 267
Tenacity, 154
Test paper, 256
Tetartohedral forms, 18
  groups, 51, 63
Tetragonal crystals, 53
  scalenohedron, 62
  symmetry, 10
  system, 53; 15
  trapezohedron, 63
  trisoctahedron, 38
  tristetrahedron, 48
Tetrahedral group, 46, 51
Tetrahedrite type, 46
Tetrahedron, 46
Tetrahexahedron, 36
Tetravalent element, 244
Theodolite goniometer, 117
Thermo-electricity, 235
Third-order prism, 59, 71
  pyramid, 59, 71
  rhombohedron, 81
Thoulet solution, 158
Tin, test for, 261, 262, 267
Titanium, test for, 264, 267
Total reflection, 169
  reflectometer, 180
Tourmaline type, 79
  tongs, 181
Translucent, 186
Transparency, 186
Transparent, 186
Trapezohedral group, 63, 78, 82
Trapezohedron, 38, 63, 74, 82
  hexagonal, 74
  tegtraonal, 63
  trigonal, 82
Tribasic acid, 244
Trichite, 140
Triclinic crystals, 106
  optical characters of, 228
  division, 74
  system, 106
  symmetry, 9
Trigonal prism, 83
  pyramid, 83
  trapezohedron, 82
  trisoctahedron, 36
  tristetrahedron, 48
Trigondodecahedron, 48
Trigonotype group, 74
Trimorphous, 251
Trisoctahedrons, 36, 38
Tri-rhombohedral group, 80
Tristetrahedrons, 48
Trivalent element, 244
Truncate, truncation, 35
Tungsten, test for, 267
Twin crystals, 118
  drawing of, 552
  optical characters, 226
Twinning axis, 119
  plane, 119
Twinning, polysynthetic, 121
  repeated, 121
  secondary, 122, 148

U

Ullmanite type, 51
Ultra-blue, 428
Uneven fracture, 152
Uniaxial crystals, 192
  optical characters, 193
  examination, 197
Unit form, 25
  prism, 54, 90, 101, 107
  pyramid, 92, 101, 107
Univalent element, 244
Unmetallic luster, 188
Uranium, tests for, 263, 264, 267
Uralitization, 401

V

Valence, 244
Vanadium, test for, 263, 264, 267
Velocity of light, 162
  relation to refractive index, 168
Vanadates, 112
Vesicular bead, 135
Vibration-directions, 197, 203, 211
  relation to ether-axes, 211
Vicinal forms, 20, 41
Vitreous luster, 188

W

Water of crystallization, 248
Water-waves, 161
Wave-front, 163
Wave-length, 162, 164

Wave-motion, 161
Wave-surface, biaxial crystals, 204
uniaxial crystals, 194
Waxy luster, 89
Westphal balance, 148
White light, 164
Widmanstätten lines, 281
Wulfenite type, 61

X

X-rays, 205

Z

Zinc, test for, 281, 287
Zircon type, 58
Zirconium, test for, 287
Zirconoid, 57
Zonal equations, 29
Zone, 26, 29
Zone-axis, 29
Zone-circle, 27
Zone-symbol, 29

INDEX TO SPECIES.

A

Aarite, *v.* Arite, 295
Abriachanite, 404
Acadialite, 458
Acanthite, 290
Acerdese, *v.* Manganite
Achmatite, 439
Achroite, 448
Acmite, 391
Actinolite, Actinote, 400
Adamantine spar, 333
Adamine, 505
Adamite, 505
Adelite, 502
Adipocire, *v.* Hatchettite
Adular, Adularia, 372
Ædelite, 442
Ægirine, 391
Ægirite, 391
Ægirite-augite, 390
Ænigmatite, 405
Æschynite, 493
Agalite, 480
Agalmatolite, 466
Agaric mineral, 356
Agate, 326
Agate-jasper, 327
Agricolite, 419
Aguilarite, 289
Aikinite, 310
Alabandin, 292
Alabandite, 292
Alabaster, 532
    Oriental, 356
Alalite, 388
Alaskaite, 308
Alaun, *v.* Alum, 535
Alaunstein, 537
Albertite, 545
Albite, 377
Alexandrite, 34
Algodonite, 286
Alisonite, 288
Allactite, Allaktit, 506
Allagite, 396
Allanite, 440
Allemontite, 275
Allochroite, 417
Alloclasite, Alloklas, 304
Allopalladium, 281
Allophane, 483
Almandine, Almandite, 416; 338
Alshedite, 486
Alstonite, *v.* Bromlite, 362
Altaite, 288
Alum, 535
Alumian, 530
Alumina, 333
ALUMINATES, 337 *et seq.*
Aluminite, 537
Aluminium borate, 518
    carbonate, 366,
    chloride, 321
    fluorides, 321, 323
    hydrates, 348, 351
    mellate, 542
    oxide, 333, 348, 351
    phosphates, 506, 510, *etc.*
    silicates, 431, 432, 433, 434, 481, 482, 483, *etc.*
    sulphates, 523, 530, 535, 537
Aluminium ore, 351
Alumstone, 537
Alunite, 537
Alunogen, 535
Alurgite, 470
Amalgam, 279
Amarantite, 536
Amazonite, 374
Amazonstone, 374
Amber, 543; 276
Amblygonite, 503
Amblystegite, 386
Amesite, 475
Amethyst, 326
    Oriental, 333
Amianthus, 401, 477
Ammiolite, 516
Ammonium, carbonate, 364
    chloride, 319
    oxalate, 542
    phosphates, 510, *etc.*
    sulphates, 523, *etc.*
Amphibole, 399
AMPHIBOLE Group, 397
Amphibole-anthophyllite, 401
Amphigène, 381
Amphodelite, 380
Analcime, 460
Analcite, 460
Anatase, 346
Andalusite, 432
Andesine, 379
Andorite, 308
Andradite, 417
Andrewsite, 514
Anglesite, 527
Anhydrite, 528
Animikite, 286
Ankerite, 358
Annabergite, 509
Annerödite, 493
Annite, 470
Anomite, 468
Anorthite, 380
Anorthoclase, Anorthose, 374
Anthophyllite, 398
    Hydrous, 398
Anthracite, 546
Antigorite, 477
Antimonarsen, *v.* Allemontite
ANTIMONATES, 516
Antimonblende, 305
Antimonglanz, 283
ANTIMONIDES, 296, *etc.*
Antimonite, 283
ANTIMONITES, 516
Antimonnickel, 296
Antimonsilber, 286
Antimonsilberblende, 311
Antimony, Arsenical, 275
    Gray, 283
    Native, 275
    Red, *v.* Kermesite
    White, 330
Antimony oxides, 330
    oxysulphide, 305
    sulphide, 283, 284
Antimonblende, *v.* Kermesite
Antimony glance, 283
Antlerite, 530

Apatite, 497
Aphanèse, Aphanesite, 505
Aphrite, 355
Aphrizite, 448
Aphrosiderite, 475
Aphthalose, 523
Aphthitalite, 523
Apjohnite, 537
Aplome, 417
Apophyllite, 452
Apotome, 526
Aquamarine, 406
Arsæoxene, 505
Aragonite, 361
Arcanite, 523
Ardennite, 445
Arendalite, 439
Arfvedsonite, 405
Argentine, 355 —CaCO3
Argentite, 288—Silver sulphide
Argentobismutite, *v.* Matildite
Argyrodite, 316
Arite, 295
Arkansite, 347
Arquerite, 279
Arragonite, *v.* Aragonite, 361
ARSENATES, 494
Arsenic, 274
  Antimonial, 275
  Native, 274
  White, 330
Arsenic oxide, 330
  sulphide, 282
ARSENIDES, 285
Arsenikalkies, 303
Arsenikkies, 303
Arseniopleite, 507
Arseniosiderite, 506
Arsenkies, 303
Arsenolite, 330
Arsenopyrite, 303
Arsensilberblende, 311
Asbestos, Asbestus, 401, 477
  Blue, 404
Asbolan, 352
Asbolite, 352
Ascharite, 519
Asmanite, 328
Asparagus-stone, 498
Aspasiolite, 408
Asphaltum, 545
Asteria, 333
Asteriated quartz, 326
  sapphire, 333
Astrakanite, 535
Astrophyllite, 487
Atacamite, 322
Atelestite, 507
Atopite, 516
Attacolite, 513
Auerlite, 430
Augelite, 513
Augite, 390
Auralite, 408
Aurichalcite, 366
Auripigmentum, 283
Automolite, 339
Autunite, 515
Aventurine feldspar, 378
  quartz, 326
Ax-stone, 394
Axinite, 441
Awaruite, 281
Azurite, 365

B

Babingtonite, 396
Baddeleyite, 346
Bagrationite, 439
Baikalite, 389
Balas ruby, 338
Baltimorite, 477
Bamlite, 484
Baricalcite, 356
Barite, 524
Barium carbonate, 362, 384
  nitrate, 517
  silicate, 378, 381, 408, 454, 456, 460, *etc.*
  sulphate, 524
Bariumuranit, 515
Barkevikite, 405
Barrandite, 510
Barsowite, 481
Barylite, 408
Barysilite, 408
Baryt, Barytes, 524
Baryta, *v.* Barium
Baryta-feldspar, 378, 381
Barytocalcite, 364
Baryturanit, 515
Basanite, 327
Bastite, 386
Bastnäsite, Bastnaesite, 364
Bathvillite, 543
Batrachite, 422
Bauxite, 350
Bayldonite, 511
Beaumontite, 454
Beauxite, 350
Bechilite, 521
Beegerite, 314
Beilstein, *v.* Nephrite
Bell-metal ore, 315
Belonesite, 542
Bementite, 484
Beraunite, 513
Bergamaskite, 402
Bergblau, *v.* Azurite
Bergkrystall, *v.* Quartz
Bergholz, 401
Bergleder, 401
Bergmannite, 461
Bergmehl, 356
Bergmilch, 356
Bergöl, 544
Bergpech, 545
Bergsalz, 318
Bergseife, 482
Bergtheer, *v.* Pittasphalt, 544
Berlinite, 518
Bernstein, 543
Berthierite, 308
Bertrandite, 446
Beryl, 405
Beryllium aluminate, 342
  borate, 518
  phosphate, 508
  silicate, 405, 407, 428, 436, 446
Beryllonite, 496
Berzelianite, 289
Berzeliite, 495
Beudantite, 516
Beyrichite, 295
Bieberite, 534
Bildstein, *v.* Agalmatolite
Bindheimite, 516
Binnite, 308
Biotina, Biotine, 381
Biotite, 467
Bischofite, 323
Bismite, 330
Bismuth, Native, 275
Bismuth arsenate, 507
  carbonate, 364, 367
  oxide, 330
  oxychloride, 323
  selenide, 284
  silicate, 414
  sulphide, 284
  tellurate, 538
  telluride, 284
  uranate, 515
  vanadate, 496
Bismuth glance, 284
Bismuth gold, 276
Bismuth ocher, 330
Bismuthinite, 284
Bismutite, 367
Bismutosmaltite, 302
Bismutosphærite, 364
Bittersalz, *v.* Epsomite
Bitter spar, Bitterspath, *v.* Dolomite
Bitumen, 544, 545
Bituminous coal, 546
Bixbyite, 343
Bjelkite, 309
Black jack, 291
Black lead, 278
Blättertellur, *v.* Nagyagite, 305
Blaueisenerde, *v.* Vivianite
Blei, Gediegen, 279
Bleiantimonglanz, 307
Bleiglanz, 287
Bleinière, Bleinierite, *v.* Bindheimite
Bleischweif, 288
Bleivitrol, 527

Blende, 291
Blödite, 535
Blœdite, Bloedite, 535
Bloodstone, 326
Blue asbestus, 404
  iron earth, 508
  john, 320
  malachite, *v.* Azurite
  vitriol, 534
Bobierrite, 508
Boghead cannel, 546
Bog-iron ore, 350
  manganese, 352
Bole, Bolus, 482
Boléite, 322
Bologna stone, 525
Boltonite, 422
Bone-phosphate, 499
  turquoise, 512
Bonsdorffite, 408
Boort, 272
Boracic acid, 352
Boracite, 518
Borates, 518
Borax, 520
Borickite, 514
Boric acid, 352
Bornite, 297
Boron hydrate, 352
  silicate, 431, 435
Boronatrocalcite, 520
Bort, 272
Bostonite, 478
Botryogen, 537
Botryolite, 436
Boulangerite, 309
Bournonite, 310
Boussingaultite, 535
Bowenite, 477
Brackebuschite, 505
Bragite, 490
Brandisite, 471
Brandtite, 507
Brauneisenstein, 350
Braunite, 343
Braunkohle, 546
Braunstein, Grauer, *v.* Pyrolusite
Brazilian pebble, 325
  emerald, 448
  sapphire, 448
Brazilite, 346
Bredbergite, 417
Breislakite, 402
Breithauptite, 296
Breunerite, 358
Breunnerite, 358
Brevicite, 461
Brewsterite, 454
Brittle silver ore, 314
Brochantite, 530
Bröggerite, 521
Bromides, 319
Bromlite, 362
Bromyrite, 319
Brongnartine, 530
Brongniardite, 309
Bronzite, 385
Brookite, 347
Brown coal, 546
  iron ore, 350
  iron stone, 350
  hematite, 350
  ocher, 350
  spar, 358
Brucite, 351
Brushite, 510
Bucholzite, 434
Bucklandite, 439, 440
Buhrstone, 327
Bunsenite, 332
Buntkupfererz, 297
Burrstone, 327
Bushmanite, 535
Bustamite, 396
Buttermilcherz, 319
Byssolite, 401
Bytownite, 379

C

Cabreite, 509
Cacholong, 329
Cacoxenite, Cacoxene, 518
Cadmia, 447
Cadmium sulphide, 294
Cadmium blende, *v.* Greenockite, 294
Cæsium silicate, 382
Cainosite, *v.* Cenosite, 483
Cairngorm stone, 326
Caking coal, 546
Calamine, 446; 360
Calaverite, 305
Calc sinter, 356
  spar, 354
  tufa, 356
Calcioferrite, 514
Calciostrontianite, 368
Calciovolborthite, 505
Calcite, 354
Calcium arsenate, 510, *etc.*
  antimonate, 516
  borate, 519, 520, *etc.*
  carbonate, 354, 361
  chloride, 321
  fluoride, 320
  iodate, 517
  molybdate, 541
  niobate, 489, *etc.*
  nitrate, 517
  oxalate, 542
  oxyfluoride, 322
  phosphate, 497, 507, 510, *etc.*
  silicate, 395, 380, *etc.*
  sulphate, 528, 531, *etc.*
  sulphide, 292
Calcium tantalate, 489
  titanate, 485, 487
  tungstate, 540
Caledonite, 530
Callainite, Callais, 510
Calomel, 317
Campylite, 500
Canaanite, 389
Cancrinite, 411
Canfieldite, 316
Cannel coal, 546
Caoutchouc, Mineral, 545
Capillary pyrites, 295
Caporcianite, 457
Cappelenite, 407
Caracolite, 530
Carbon, 272
Carbonado, 272
Carbonates, 353
Carminite, 496
Carminspath, 496
Carnallite, 323
Carnelian, 326
Carneol, *v.* Carnelian
Carpholite, 447
Carphosiderite, 536
Carrollite, 297
Caryinite, 495
Caryocerite, 407
Caryopilite, 484
Cassiterite, 344
Castanite, 536
Castor, Castorite, 369
Caswellite, 469
Catapleiite, 407
Cataspilite, 408
Cat's-eye, 342, 326
Cauk, Cawk, 525
Celadonite, 481
Celestine, 526
Celestite, 526
Celsian, 381
Cenosite, 483
Cerargyrite, 319
Cerite, 447
Cerium carbonate, 364
  fluoride, 321, 322
  niobates, 489
  phosphates, 495, 509
  silicates, 440 447, 487, *etc.*
Cerussite, Cerusite, 363
Cervantite, 330
Ceylanite, Ceylonite, 338
Chabasie, 458
Chabazite, 458
Chalcanthite, 534
Chalcedony, 326
Chalcocite, 290
Chalcodite, 476
Chalcomenite, 538
Chalcophanite, 352
Chalcophyllite, 511
Chalcopyrite, 297
Chalcosiderite, 514

Chalcolite h 515

Chalcosine, 290
Chalcostibite, 303
Chalcotrichite, 331
Chalk, 356
    French, 479
Chalybite, 359
Chamoisite, Chamosite, 476
Chathamite, 301
Chemawinite, 543
Chenevixite, 514
Chert, 327
Chessy copper, 365
Chessylite, 365
Chesterlite, 374
Chiastolite, 433
Childrenite, 518
Chilenite, 286
Chiolite, 321
Chiviatite, 307
Chladnite, 384
Chloanthite, 301
Chloraluminite, 321
Chlor-apatite, 498
Chlorblei, *v.* Cotunnite
CHLORIDES, 317
Chlorite, 472
CHLORITE Group, 472
Chloritoid, 471
Chloritspath, 471
Chlorocalcite, 321
Chloromagnesite, 321
Chloromelanite, 394
Chloropal, 484
Chlorophæite, 475
Chlorophane, 320
Chlorophyllite, 408
Chlorquecksilber, 317
Chlorospinel, 338
Chlorsilber *v.* Cerargyrite
Chondrarsenite, 505
Chondrodite, 443
Chrismatine, Chrismatite, 543
Christianite, 381
Christobalite, 328
Christophite, 291
CHROMATES, 529, *etc.*
Chrome diopside, 389
Chrome spinel, 338
Chromeisenstein, *v.* Chromite
Chromic iron, 341
Chromite, 341
Chromium oxide, 341
    sulphate, 537
    sulphide, 297
Chrysoberyl, 342
Chrysocolla, 483
Chrysolite, 420
CHRYSOLITE Group, 419
Chrysoprase, 326
Chrysotile, 477
Churchite, 509
Cimolite, 482
Cinnabar, 293
    Inflammable, 544
Cinnamon-stone, 416
Cirrolite, 506
Citrine, 326
Clarite, 315
Claudetite, 330
Clausthalite, 288
Clay, 481 *et seq.*
Clay iron-stone, 385
    Brown, 350
Cleavelandite, 378
Cleiophane, 292
Cleveite, 521
Cliftonite, 278
Clinochlore, 473
Clinoclase, 505
Clinoclasite, 505
Clinohedrite, 447
Clinohumite, 443
Clintonite, 471
CLINTONITE Group, 470
Clinozoisite, 489
Coal, Mineral, 545, 546
Cobalt arsenate, 507, 509
    carbonate, 361, 367
    arsenide, 301, 302, 303, 304
    selenite, 538
    sulph-arsenide, 301
    sulphate, 534
Cobalt sulphide, 301
Cobalt bloom, 509
Cobalt glance, *v.* Cobaltite
Cobaltine, 301
Cobaltite, 301
Cobaltomenite, 538
Coccolite, 389
Cœlestine, 526
Cœruleolactite, 518
Cohenite, 281
Coke, 546
Colemanite, 519
Cölestine, *v.* Celestite
Collophanite, 507
Collyrite, 483
Colophonite, 417, 428
Coloradoite, 292
COLUMBATES, *v.* NIOBATES, 489
Columbite, 490
Comptonite, 463
Confolensite, 482
Conichalcite, 511
Connarite, 480
Connellite, 530
Cookeite, 467
Copal, Fossil, 543
Copaline, Copalite, 543
Copiapite, 536
Copper, 278
    Emerald, *v.* Dioptase, 424
    Gray, 312
    Indigo, *v.* Covellite, 294
    Native, 278
    Red, *v.* Cuprite, 330
Copper, Vitreous, *v.* Chalcocite, 290
    Yellow, 297
Copper arsenate, 504, 505, 511, *etc.*
    arsenide, 286
    carbonate, 364, 365
    chloride, 317, 322, 323
    manganate, 348
    iodide, 317, 319
    nitrate, 517
    oxides, 331, 333
    oxychlorides, 322, 323
    phosphates, 504, 511, *etc.*
    selenides, 289
    selenite, 538
    silicates, 424, 483
    sulphantimonate, 315
    sulphantimonites, 303 *et seq.*
    sulpharsenates, 315
    sulpharsenite, 303, *etc.*
    sulphates, 528, 530; hydrous, 534 *et seq.*
    sulphides, 290, 294, 297 *et seq.*
    sulpho-bismuthites, 303
    tungstate, 541
    vanadates, 505
Copper glance, 290
Copper mica, 515
Copper nickel, 295
Copper pyrites, 297
Copper uranite, 515
Copper vitriol, 534
Copperas, 534
Coprolites, 499
Coquimbite, 535
Cordierite, 407
Cornwallite, 511
Corundophilite, 475
Corundum, 333
Corynite, 302
Cosalite, 309
Cossyrite, 405
Cotunnite, 321
Couseranite, 426
Covellite, Covelline, 294
Crednerite, 343
Crichtonite, 337
Cristobalite, 328
Crocalite, 462
Crocidolite, 404
Crocoite, Crocoisite, 529
Cromfordite, *v.* Phosgenite
Cronstedtite, 475
Crookesite, 289
Crossite, 405
Cryolite, 321
Cryophyllite, 467
Cryptolite, 495
Cryptoperthite, 378
Cuban, 297
Cubanite, 297

Cube ore, *v.* Pharmacosiderite
Cube spar, *v.* Anhydrite
Culsageeite, 476
Cumengite, 322
Cummingtonite, 401
Cuprite, 330
Cuprobismutite, 307
Cuprodescloizite, 505
Cuproiodargyrite, 319
Cuproplumbite, 288
Cuproscheelite, 541
Cuprotungstite, 541
Cuspidine, 441
Cyanite, 434
Cyanochroite, 535
Cyanotrichite, 536
Cyclopite, 380
Cylindrite, 316
Cymatolite, 393
Cymophane, 342
Cyprine, 428
Cyprusite, 537
Cyrtolite, 430

D

Dahllite, 499
Damourite, 465
Danaite, 304
Danalite, 414
Danburite, 431
Dannemorite, 401
Darapskite, 517
Datholite, 435
Datolite, Datolith, 435
Daubreeite, Daubreite, 322
Daubréelite, 297
Davidsonite, 406
Daviesite, 322
Davyne, Davina, 411
Dawsonite, 366
Dechenite, 505
Delessite, 475
Delphinite, 439
Delvauxite, Delvauxene, 513
Demant, *v.* Diamond, 271
Demantoid, 417
Derbylite, 516
Derbyshire spar, 320
Descloizite, 505
Desmine, 456
Destinezite, 516
Dewalquite, 445
Deweylite, 479
Diabantite, 475
Diadochite, 516
Diallage, 389
Diallogite, Dialogite, 359
Diamant, 271
Diamond, 271
Diamond, Bristol, Lake George, 325
Dianite, 491
Diaphorite, 309
Diaspore, 348
Diatomite, 329
Dichroite, 407
Dickinsonite, 507
Dietrichite, 535
Dietzeite, 517
Dihydrite, 505
Diopside, 388
Dioptase, 424
Dipyre, 426
Disterrite, 471
Disthene, 434
Dog-tooth spar, 355
Dolerophanite, 530
Dolomite, 357
Domeykite, 286
Domingite, 308
Doppelspath, 355
Dopplerite, 544
Double-refracting spar, 355
Douglasite, 323
Dreelite, 525
Dry-bone, 360
Dudleyite, 476
Dufrenite, 506
Dufrenoysite, 309
Dumortierite, 449
Durangite, 503
Durdenite, 538
Dysanalyte, 488
Dyscrasite, 286
Dysluite, 339
Dysodile, 544
Dyssnite, 396
Dysyntribite, 410, 466

E

Ecdemite, 516
Écume de Mer, 480
Edelite, 442
Edenite, 402
Edingtonite, 460
Egeran, 428
Ehlite, 505
Eichwaldite, 518
Eisen *v.* Iron 281
Eisenblau, *v.* Vivianite
Eisenblüthe, 361
Eisenglanz, 334
Eisenglimmer, 335
Eisenkies, 300, 303
Eisennickelkies, 293
Eisenplatin, 280
Eisenrahm, 335
Eisenrosen, 335
Eisenspath, 359
Eisenstassfurtite, 519
Eisspath, 372
Eisstein, 321
Ekdemite, 516
Elæolite, 410
Elaterite, 545
Electrum, 276, 543
Elements, 271 *et seq.*
Eleolite, 410
Eleonorite, 513
Elpidite, 407
Embolite, 319
Embrithite, 309
Emerald, 406
  Oriental, 406
  Uralian, 418
Emerald copper, *v.* Dioptase, 424
Emerald nickel, 367
Emery, 333
Emmonsite, 538
Emplectite, Emplektit, 308
Enargite, 315
Endellionite, *v.* Bournonite, 310
Endlichite, 501
Enstatite, 384
Eosphorite, 514
Epiboulangerite, 315
Epichlorite, 475
Epididymite, 369
EPIDOTE Group, 437
Epidote, 438
Epigenite, 315
Epistilbite, 454
Epsom salt, 533
Epsomite, 533
Erbium niobate, 490, 493
Erbsenstein 356
Erdkobalt, *v.* Asbolite
Erdöl, 544
Erdpech, 545
Erdwachs, 543
Erinite, 505
Erubescite, 297
Erythrite, 509
Erythrosiderite, 323
Erythrozincite, 295
Esmarkite, 408
Essonite, 416
Ettringite, 538
Eucairite, 289
Euchroite, 511
Euclase, 436
Eucolite, 407
Eucolite-titanite, 486
Eucryptite, 410
Eudialyte, 407
Eudidymite, 369
Eudyalite, 407
Eugenglanz, 314
Eukairite, 289
Euklas, 436
Eulytine, 414
Eulytite, 414
Eupyrchroite, 498
Euralite, 475
Eusynchite, 505
Euxenite, 493
Evansite, 513

F

Facellite, 410
Fahlerz, Fahlore, 312
Fahlunite, 408
Fairfieldite, 507
Falkenhaynite, 312
Famatinite, 315
Faserkiesel, 434
Faserzeolith, v. Natrolite
Fassaite, 390
Faujasite, 460
Fayalite, 422
Feather-alum, v. Halotrichite
Feather-ore, 309
Federerz, 309
FELDSPAR Group, 369
Feldspar, Baryta, 373, 381
  Blue v. Lazulite
  Common, 373
  Glassy, 372
  Labrador, 379
  Lime, 380
  Potash, 370, 373
  Soda, 377
Felsöbanyite, 537
Felspar, v. Feldspar
Fergusonite, 490
FERRATES, 337
Ferrocalcite, 356
Ferrogoslarite, 533
Ferronatrite, 536
Feuerblende v. Pyrostilpnite, 312
Fibroferrite. 536
Fibrolite, 433
Fichtelite, 543
Fiedlerite, 322
Fillowite, 507
Fiorite, 329
Fire opal. 329
  marble, 356
Fireblende v. Pyrostilpnite, 312
Fischerite, 512
Flèches d'amour, 345
Flinkite, 506
Flint, 327
Float-stone, 329
Flos ferri, 361
Fluellite, 323
Fluocerite, 322
Fluor v. Fluorite,
Fluor-apatite, 498
Fluor spar, 320
FLUORIDES, 320 *et seq.*
Fluorite, 320
Flussspath, 320
Foliated tellurium v. Nagyagite, 305
Fontainebleau limestone, 355
Footeite. 323
Forbesite, 510
Forsterite, 422
Fossil copal, 543
  wood, 326, 328
Fouquéite, 420
Fowlerite, 396
Franckeite, 316
Francolite, 498
Franklinite, 341
Fraueneis, v. Selenite
Frauenglas, v. Mica
Fredricite, 313
Freibergite, 313
Freieslebenite, 300
French chalk, 479
Frenzelite, 284
Friedelite, 494
Frieseite, 300
Fuchsite, 466

G

Gadolinite, 408
Gahnite, 336
Galactite, 461
Galapectite, 480
Galena, Galenite, 287
Galena, False, 291
Galenobismutite, 306
Galmei, 446
Ganomalite, 406
Ganophyllite, 458
Garnet, 415
  Cinnamon, 416
  Chrome, 417
  Grossular, 416
  Oriental, 416
  Precious, 416
  Tetrahedral, v. Helvite
  White, v. Leucite
Garnierite, 479
Gastaldite, 404
Gay-Lussite, 366
Gearksutite. 323
Gedanite. 543
Gedrite, 398
Gehlenite, 427
Geikielite. 488
Gekrösstein, 528
Gelbbleierz. 541
Gelbeisenerz, 537
Gelbeisenstein, 350
Genthite, 479
Geocerellite, 544
Geocerite, 544
Geocronite, 314
Geomyricite, 544
Gerhardtite, 517
GERMANATES, 316
Gersdorffite, 302
Geyerite, 303
Geyserite, 329
Gibbsite, 351
Gieseckite, 410, 466
Gigantolite, 408, 466
Gilbertite, 465
Gilsonite. 545
Gips, v. Gypsum
Girasol, 329
Gismondine, 457
Gismondite, 457
Glance coal, 546
  Cobalt, v. Cobaltite
  Copper, v. Chalcocite
Glanzeisenerz, 335
Glanzkohle, 546
Glaserite, v. Aphthitalite
Glaskopf, Brauner, 350
  Rother, v. Hematite, 335
Glassy Feldspar, 372
Glauber salt, 531
Glauberite, 528
Glaucodot, 304
Glaucolite, 426
Glauconite, 481
Glaucophane, 403
Glaukodot, 304
Glessite, 543
Glimmer, v. Mica
Globosite, 513
Glockerite, 536
Glucinum, v. Beryllium
Gmelinite, 459
Goethite, 349
Gold, 275
Gold tellurides, 304, 305
Goshenite, 406
Goslarite, 533
Göthite, 349
Goyazite. 514
Grahamite, 545
Gramenite, Graminite, 484
Grammatite, 401
Granat, v. Garnet
Graphic tellurium, 304
Graphite, 273
Gray antimony, 283
  copper, 312
Green lead ore, 499
Greenockite, 294
Greenovite, 486
Grenat, v. Garnet
Griphite, 502
Grossular. Grossularite, 416
Grothite, 486
Grünauite, 296
Grünbleierz, 499
Grüneisenerde, v. Dufrenite
Grünerite, 401
Guadalcazarite, 292
Guanajuatite, 284
Guano, 499
Guarinite, 487
Guejarite, 308
Guitermanite, 310
Gummierz, 522
Gummite, 522
Gymnite, 479
Gypsum, Gyps, 531
Gyrolite, 452

H

Haarkies, 295, 303
Haarsalz, 533
Hæmatite, *v.* Hematite, 334
Haidingerite, 510
Hair salt, 533
Halite, 318
Hallite, 476
Halloysite, 481
Halotrichite, 535
Hamartite, 364
Hambergite, 518
Hamlinite, 503
Hanksite, 530
Hannayite, 510
Haplome, 417
Harlequin opal, *v.* Opal
Harmotome, 456
Harstigite, 442
Hartite, 543
Hastingsite, 402
Hatchettine, Hatchettite, 543
Hatchettolite, 489
Hauchecornite, 295
Hauerite, 301
Haughtonite, 468
Hausmannite, 342
Hautefeuillite, 508
Haüyne, 412
Haüynite, 412
Haydenite, 458
Heavy spar, 524
Hebronite, 503
Hedenbergite, 389
Hedyphane, 501
Heintzite, 520
Heliophyllite, 516
Heliotrope, 326
Helvite, Helvine, 414
Hemafibrite, 511
Hematite, 334
    Brown, 350
Hematolite, 507
Hematostibiite, 507
Hemimorphite, 446
Henwoodite, 514
Hepatic cinnabar, 294
Hercynite, 339
Herderite, 503
Herrengrundite, 536
Herschelite, 458
Hessite 289
Hessonite, 416
Heteroclin, 343
Heulandite, 454
Hielmite, Hjelmit, 493
Hieratite, 321
Hiddenite, 393
Highgate resin, 543
Himbeerspath, 359
Hintzeite, 520
Hiortdahlite, 396
Hisingerite, 484
Hoeferite, 484
Hœrnesite, 508
Hohmannite, 536
Holzopal, 329
Holzzinnerz, 344
Homilite, 436 Homichlin
Honey-stone, Honigstein, *v.* Mellite
Hopeite, 507
Horbachite, 296
Horn quicksilver, 317
Horn silver, 319
Hornblei, *v.* Phosgenite
Hornblende, 399, 402
Hörnesit, Hornsilber, 319
Hornstone, 327
Horse-flesh ore, 297
Horsfordite, 286
Hortonolite, 423
Howlite, 519
Huantajayite, 318
Hübnerite, 539
Hullite, 475
Humboltine, 542
Humboldtilite, 426
Humboldtite, 436
Humite, 443
Huntilite, 286
Hureaulite, 510
Hyacinth, 429; 416
Hyalite, 329
Hyalophane, 373
Hyalosiderite, 420
Hyalotekite, 408
Hydrargillite, 351
Hydraulic limestone, 356
Hydroboracite, 521
HYDROCARBONS, 543
Hydrocerussite, 366
Hydrocyanite, 528
Hydrofranklinite, 352
Hydrogiobertite, 367
Hydrohematite, 350
Hydromagnesite, 367
Hydromica, 465
Hydromuscovite, 465
Hydronephelite, 463
Hydrophane, 329
Hydrophilite, 321
Hydrotalcite, 352
Hydrozincite, 366
Hypersthene, 385
Hypostilbite, 457

I

Iberite, 408
Ice, 331
Ice spar, 372
Iceland spar, 355
Iddingsite 422
Idocrase, 427
Idrialine, Idrialite, 544
Igelströmite, 352
Ihleite, 535
Ilesite, 533
Ilmenite, 336
Ilmenorutile, 345
Ilvaite, 445
Indianaite, 482
Indianite, 380
Indicolite, 448
Indigolite, 448
Inesite, 452
Inflammable cinnabar, 544
Infusorial earth, 329
Iodate of calcium, 517
IODIDES, 319
Iodobromite, 319
Iodyrite, 319
Iolite, 407
    Hydrous, 408
Iridium, Native, 280
Iridosmine, 280
Iron, Chromic, *v.* Chromite
    Magnetic, 339
    Meteoric, 281
    Native, 281
    Oligist, *v.* Hematite
Iron aluminate, 339
    arsenates, 508, 509, *etc.*
    arsenides, 303
    carbide, 281
    carbonate, 359
    chlorides, 321
    chromate, 341
    columbate, 490
    ferrate, 339
    hydrates, 349, 350, *etc.*
    niobate, 490
    oxalate, 542
    oxide, 334, 339; hydrated, 349, 350
    phosphates, 506, 508, 510, *etc.*
    silicates, 422, 445, 475, 476
    sulphantimonite, 308
    sulpharsenide, 303
    sulphates, 534, 535, 536, *etc.*
    sulphides, 293, 296, 300, 303
        magnetic, 296
    tantalates, 490
    tellurite, 538
    titanates, 336, 343
    tungstates, 539, 542
Iron alum, 535
Iron natrolite, 461
Iron pyrites, 300, 303
    Magnetic, 296
    White, 303
Iserine, Iserite, 337
Isoclasite, 511
Itabirite, 336
Itacolumite, 327

J

Jacobsite, 341
Jade, 393, 394, 401
Jade tenace, 394
Jadeite, 393
Jalpaite, 289
Jamesonite, 308
Jargon, 429
Jarosite, 537
Jasper, 337
Jaspopal, 339
Jefferisite, 476
Jeffersonite, 390
Jeremejevite, 518
Jet, 546
Johannite, 538
Johnstrupite, 487
Jordanite, 313
Joseite, 285
Josephinite, 281

K

Kaersutite, 402
Kainite, 530
Kakoxen, 513
Kaliborite, 520
Kalifeldspath, *v.* Orthoclase
Kaliglimmer, 464
Kalinite, 535
Kaliophilite, 410
Kalisalpeter, *v.* Niter
Kalkglimmer, 470
Kalkspath, 354
Kalkuranit, 515
Kallait, *v.* Turquois
Kallilite, 302
Kalomel, 317
Kaluszite, 534
Kamacite, 281
Kämmererite, 474
Kamarezite, 536
Kammkies, 303
Kampylite, 499
Kaolin, 481
Kaolinite, 481
Karminspath, *v.* Carminite
Karneol, *v.* Carnelian
Karstenite, *v.* Anhydrite
Karyinite, 495
Kataforite, 402
Katzenauge, *v.* Cat's-eye
Kautschuk, fossiles, 545
Kehoeite, 514
Keilhauite, 487
Kelyphite, 418
Kentrolite, 446
Kermes, 305
Kermesite, 305
Kerosene, 544
Kerrite, 476
Kibdelophan, 337
Kidney ore, 335
    stone, 401
Kieselwismuth, 414
Kieselzinkerz, 446
Kieserite, 531
Kilbrickenite, 314
Killinite, 466
Kjerulfine, 502
Klaprotholite, 307
Klinoklas, 505
Klinozoisit, 489
Knebelite, 423
Knopite, 488
Knoxvillite, 536
Kobaltblüthe, 509
Kobaltglanz, *v.* Cobaltite
Kobaltkies, *v.* Linnæite
Kobaltspath, *v.* Sphærocobaltite
Kobellite, 309
Kochsalz, *v.* Halite
Koettigite, 509
Kohle, 545, 546
Kohlenspath, *v.* Whewellite
Kokscharovite, 403
Kongsbergite, 279
Königine, Königite, 530
Koninckite, 510
Koppite, 489
Kornerupine, 451
Korund, *v.* Corundum
Kotschubeite, 473
Köttigite, 509
Krantzite, 543
Kraurite, 506
Kreittonite, 339
Kremersite, 323
Krennerite, 305
Krisuvigite, 530
Kröhnkite, 536
Krönkite, Krönnkite, 536
Kryptoperthit, 373
Kupfer, *v.* Copper
Kupferantimonglanz, 308
Kupferblende, 313
Kupferglanz, *v.* Chalcocite
Kupferglimmer, *v.* Chalcophyllite
Kupferindig, 294
Kupferkies, 297
Kupferlasur, 365
Kupfernickel, 295
Kupferschaum, 511
Kupferuranit, 515
Kupfervitriol, 534
Kupfferite, 402
Kyanite, 434
Kylindrite, 316

L

Labrador feldspar, 379
Labradorite, 379
Lagonite, 519
Lampadite, 352
Lanarkite, 530
Långbanite, 446
Langbeinite, 533
Langite, 536
Lansfordite, 367
Lanthanite, 366
Lanthanum carbonate, 366
Lapis-lazuli, 418
Larderellite, 519
Lasurapatite, 493
Lasurite, 418
Latrobite, 380
Laubanite, 457
Laumonite, 457
Laumontite, 457
Laurionite, 323
Laurite, 303
Lautarite, 517
Låvenite, 395
Lavroffite, Lavrovite, 389
Lawrencite, 331
Lawsonite, 447
Lazulite, 506
Lazurite, 418
Lead, 279
    Black, 278
    Native, 279
    White, *v.* Cerussite
Lead antimonate, 516
    arsenates, 500
    carbonates, 363, 366
    chloride, 321, 322
    chloro-carbonates, 364
    chromates, 539
    dioxide, 346
    molybdate, 541
    oxides, 332, 343, 346
    oxychlorides, 322
    phosphate, 499
    selenides, 288, 289
    silicates, 408, 446
    sulphantimonate, 315
    sulphantimonites, 308, *etc.*
    sulpharsenites, 308, *etc.*
    sulphates, 527, *etc.*
    sulphato-carbonate, 529
    sulphide, 287
    sulphobismuthites, 308, *etc.*
    telluride, 288
    tungstate, 541
    vanadates, 500, 505
Lead glance, 287
Lead vitriol, *v.* Anglesite
Leadhillite, 529
Lecontite, 531
Ledererite, 459
Lederite, 486
Lehrbachite, 289
Lennilite, 476
Leonhardite, 457
Leonite, 535
Leopoldite, 319
Lepidolite, 467
Lepidomelane, 470

Lepolite, 380
Lettsomite, 536
Leucaugite, 390
Leuchtenbergite 473
Leucite, 381
Leucochalcite, 511
Leucomanganite, 507
Leucopetrite, 544
Leucophanite, 407
Leucopyrite, 303
Leucoxene, 387, 486
Levynite, Levyne, 459
Lewisite, 516
Libethenite, 504
Liebenerite, 410, 466
Liebigite, 367
Lievrite, 445
Lignite, 546
Ligurite, 486
Lillianite, 310
Lime, *v.* Calcium
Lime uranite, 515
Limestone, 357
  Hydraulic, 357
  Magnesian, 358
Limonite, 350
Linarite, 530
Lindackerite, 516
Linnæite, 297
Linsenkupfer, *v.* Liroconite, 514
Linsenerz,
Lintonite, 462
Liroconite, 514
Liskeardite, 518
Lithia mica, 467
Lithionglimmer, 467
Lithiophilite, 496
Lithium phosphates, 496, 508
  silicates, 393, 410, 467
Lithographic stone, 356
Lithomarge, 481
Livingstonite, 307
Loadstone, Lodestone, 339
Loeweite, 535
Loewigite, 538
Löllingite, 303
Lorandite, 308
Lossenite, 516
Löweite, 535
Löwigite, 538
Loxoclase, 372
Luckite, 534
Ludlamite, 518
Ludwigite, 518
Lumachelle, 356
Lüneburgite, 516
Lussatite, 326
Lutecite, 328
Luzonite, 315
Lydian stone, 327

M

Mackintoshite, 437
Macle, 433
Maconite, 476
Magnesioferrite, 341
Magnesite, 358
Magnesium aluminate, 338
  arsenate, 508
  borate, 519, 520
  carbonates, 358, 366, 367
  ferrate, 341
  fluoride, 321
  hydrate, 351
  molybdate, 542
  oxides, 331, 351
  phosphates, 502, 508, 510
  silicates, 384, 385, *etc;* 419, 443, 476, 479, 480
  sulphates, 531, 533
  titanate, 488
Magneteisenstein, 339
Magnetic iron ore, 339
Magnetic pyrites, 296
Magnetite, 339
Magnetkies, 296
Magnoferrite, 341
Malachite, 364
  Blue, *v.* Azurite
  Green, 364
Malacolite, 388
Malacon, Malakon, 430
Maldonite, 276
Malinowskite, 318
Mallardite, 534
Maltha, 544
MANGANATES, 337
Manganandalusite, 433
Manganapatite, 498
Manganblende, 292
Manganbrucite, 351
Manganchlorite, 474
Manganepidote, 440
Manganese antimonate, 507
  arsenates, 502, 505, 506, 507
  carbonate, 359
  oxides, 345
  disulphide, 301
  hydrates, 349, 351, 352
  niobate, 490
  oxides, 332, 342, 343, 345, 347, 349, 351
  phosphates, 496, 502, 507
  silicates, 395, 422, 484, *etc.*
  sulphates, 531, 534
  sulphide, 292, 301
  tantalate, 490
  titanate, 387
  tungstate, 539
Manganglanz, 292
Mangangranat, *v.* Spessartite
Manganhedenbergite, 389
Manganite, 349
Manganmagnetite, 340
Manganocalcite, 356, 360
Manganocolumbite, 491
Manganophyllite, 468
Manganosiderite, 360
Manganosite, 332
Manganostibiite, 507
Manganotantalite, 491
Manganpectolite, 395
Manganspath, 359
Mangantantalite, 492
Marble, 356
  Verd-antique, 477
Marcasite, 302
Marceline, 343, 396
Margarite 470
Margarodite, 465
Marialite, 426
Marmatite, 291
Marmolite, 477
Marshite, 317
Martinite, 510
Martite, 336
Mascagnite, 523
Maskelynite, 380
Masonite, 472
Massicot, 332
Masrite, 535
Matildite, 308
Matlockite, 322
Mauzeliite, 516
Maxite, 529
Mazapilite, 514
Meerschaum, 480
Meionite, 425
Melaconite, 332
Melanasphalt,
Melanglanz, 314
Melanite, 417
Melanocerite, 407
Melanophlogite, 328
Melanotekite, 446
Melanterite, 534
Melilite, Mellilite, 426
Melinophane, *v.* Meliphanite
Meliphanite, 407
Mellate of aluminium, 542
Mellite, 542
Melonite, 297
Menaccanite, 386
Mendipite, 322
Mendozite, 535
Meneghinite, 313
Menilite, 329
Mennige, 343
Mercury, 279
  Horn, 317
  Native, 279
Mercury antimonite, 516
  chloride, 317
  selenides, 292
  sulphides, 292, 293
  sulpho-selenide, 292
  telluride, 292
Mercury amalgam, 279
Meroxene, 468

Mesitite, Mesitine, 359
Mesitinspath, 359
Mesole, v. Thomsonite
Mesolite, 463
Mesotype, 463
Messelite, 507
Metabrushite, 510
Metacinnabarite, 292
Metastibnite, 284
Metavoltine, 537
Meteoric iron, 281
Mexican onyx, 356
Miargyrite, 308
MICA Group, 463
Mica, Iron, 467, 470
  Lime, 470
  Lithia, 467
  Magnesia, 467, 469
  Potash, 464
  Soda, 467
  Vanadium, 470
Micaceous iron ore, 335
Michel-lévyte, 525
Microcline, 378
Microcosmic salt, 510
Microlite, 499
Microsommite, 411
Microperthite, 378
Microphyllite, 379
Microplakite, 379
Miersite, 319
Miesite, 499
Mikroklin, 378
Milarite, 369
Milky quartz, 326
Millerite, 295
Mimetene, Mimetesite, 500
Mimetite, 500
Mineral caoutchouc, 545
Mineral coal, 545
  oil, 544
  pitch, 545
  resin, 543
  tallow, 543
  tar, v. Pittasphalt
  wax, 543
Minium, 343
Mirabilite, 531
Misenite, 530
Mispickel, 303
Misy, 536
Mixite, 515
Mizzonite, 426
Mocha stone, v. Moss agate
Mock lead, 291
Molybdänbleispath, 541
Molybdänglanz, 285
MOLYBDATES, 539
Molybdenum sulphide, 285
  trioxide, 330
Molybdenite, 285
Molybdic ocher, 330
Molybdite, 330
Molybdomenite, 538
Molysite, 321
Monazite, 495
Monetite, 507
Monheimite, 360
Monimolite, 496
Monite, 507
Monrolite, 434
Montanite, 536
Monticellite, 423
Montmorillonite, 483
Moonstone, 372, 377
Mordenite, 453
Morenosite, 538
Morion, 326
Moroxite, 498
Mosandrite, 487
Moss agate, 326
Mottramite, 505
Mountain cork, 401
  leather, 401
  soap, 483
  tallow, 543
  wood, 401
Muller's glass, 329
Mullicite, 506
Mundic, v. Pyrite
Murchisonite, 372
Muscovite, 464
Muscovy glass, 466

N

Nadeleisenerz, v. Göthite
Nadelerz, v. Aikinite
Nadelzeolith, 461
Nadorite, 516
Nagyagite, 305
Nailhead spar, 355
Nantokite, 317
Napalite, 543
Naphtha, 544
NATIVE ELEMENTS, 271
Natrium, v. Sodium
Natroborocalcite, 520
Natrolite, 461
Natron, 366
Natronmikroklin, 374
Natronorthoklas, 372
Natrophilite, 496
Naumannite, 288
Needle ironstone, 349
Needle ore, v. Aikinite
Needle zeolite, v. Natrolite, 461
Nemalite, 351
Neotocite, 396, 484
Nepheline, 409
Nephelite, 409
Nephrite, 394, 401, 477
Neptunite, 487
Nesquehonite, 366
Nevjanskite, 280
Newberyite, 510
Newtonite, 482
Niccolite, 295
Nickel antimonide, 296
  arsenates, 509
  arsenides, 295, 301, 304
  carbonate, 367
  oxides, 333
  silicate, 479
  sulphantimonide, 303
  sulpharsenide, 302, 304
  sulphate, 533
  sulphides, 293, 295, 296
  telluride, 297
Nickel telluride, 297
Nickelantimonglanz, v. Ullmannite
Nickelarsenikglanz, v. Gersdorffite
Nickel-gymnite, 479
Nickel-skutterudite, 303
Nigrine, 345
NIOBATES, 489
Niter, Nitre, 517
Niter, Soda, 577
NITRATES, 517
Nitrobarite, 517
Nitrocalcite, 517
Nitroglauberite, 517
Nitromagnesite, 517
Nivenite, 521
Nocerite, 322
Nontronite, 484
Nordenskiöldine, 518
Nordmarkite, 450
Northupite, 364
Nosean, Nosite, 418
Noselite, 418
Noumeite, 479
Nugget, 277
Nussierite, 499

O

Ocher, Brown, 350
  Red, 335
Ochrolite, 516
Octahedrite, 346
Odontolite, 512
Œil de chat, 326
Œllacherite, 466
Oil, Mineral, 544
Oisanite, 439
Okenite, 452
Oldhamite, 292
Oligist iron v. Hematite,
Oligoclase, 378
Oligomite, 359
Olivenerz, 504
Olivenite, 504
Olivine, 420
Omphacite, Omphazit, 389
Oncosin, 465
Onofrite, 292
Onyx, 326
  Mexican, 356

Onyx marble, 356
Oölite, 356
Opal, 329
Opal jasper, 329
Ophicalcite, 477
Ophiolite, 477
Ophite, 478
Orangite, 430
Oriental alabaster, 356
  amethyst, 333
  emerald, 333
  ruby, 333
  topaz, 333
Orpiment, 282
Orthite, 440
Orthoclase, 370
Orthose, *v.* Orthoclase
Osmelite, 395
Osmiridium, 280
Osmium sulphide, 302
Osteolite, 498
Ottrelite, 471
Ouvarovite, 417
Owenite, 475
OXALATES, 542
Oxammite, 542
OXIDES, 324
OXYCHLORIDES, 322
OXYFLUORIDES, 323
OXYSULPHIDES, 305
Ozarkite, 462
Ozocerite, Ozokerit, 543

P

Pachnolite, 323
Pagodite, 466
Paisbergite, 396
Palladium, Native, 281
Panabase, *v.* Tetrahedrite
Pandermite, 520
Paposite, 536
Paraffin, 543
Paragonite, 467
Paraluminite, 537
Paramelaconite, 332
Parasite, 519
Pargasite, 402
Parisite, 364
Parophite, 466
Parrot coal, 546
Partschinite, Partschin, 419
Pearceite, 315
Pearl sinter, 329
Pearl-spar, 357
Peat, 546
Pebble, Brazilian, 325
Pechblende, Percherz, 521
Peckhamite, 387
Pectolite, 395
Peganite, 512
Pencil-stone, 482
Penfieldite, 322
Pennine, 474
Penninite, 474
Pentlandite, 293
Peplolite, 408
Percylite, 322
Periclase, 331
Pericline, Periklin, 377
Peridot, 420
Peristerite, 377
Perthite, 373
Perofskite, 487
Perovskite, 487
Perowskit, 487
Petalite, 369
Petrified wood, 327
Petroleum, 544
Petzite, 289
Phacelite, Phacellite, 410
Phacolite, 458
Pharmacolite, 510
Pharmacosiderite, 513
Phenacite, Phenakit, 423
Phengite, 466
Philadelphite, 476
Phillipite, 536
Phillipsite, 455
Phlogopite, 469
Phœnicite, 529
Phœnicochroite, 529
Pholerite, 481
Pholidolite, 481
Phosgenite, 364
PHOSPHATES,
Phosphorite, 498
Phosphorsalz, 510
Phosphosiderite, 510
Phosphuranylite, 515
Photicite, 396
Phyllite, 471
Physalite, 432
Picite, 513
Pickeringite, 535
Picotite, 338
Picroepidote, 439
Picrolite, Pikrolit, 477
Picromerite, 535
Picropharmacolite, 508
Piedmontite, 440
Pinakiolite, 518
Pinguite, 484
Pinite, 466, 408
Pinnoite, 520
Piotine, 480
Pirssonite, 366
Pisanite, 534
Pisolite, 356
Pistacite, Pistazit, 438
Pistomesite, 359
Pitch, Mineral,
Pitchblende, 521
Pittasphalt, 544
Pitticite, Pittizit, 516
Plagioclase, 374
Plagionite, 308
Plasma, 326
Plaster of Paris, 533
Platina, Platine, 280
Platiniridium, 280
Platinum, Native, 280
Platinum, arsenide, 302
Plattnerite, 346
Plenargyrite, 308
Pleonaste, 338
Plessite, 281
Plumbago, 273
Plumbogummite, 514
Plombocalcite, 356
Plumbostib, 309
Polianite, 345
Pollucite, Pollux, 382
Polyadelphite, 417
Polyargite, 466
Polyargyrite, 315
Polyarsenite, 502
Polybasite, 314
Polycrase, 493
Polychroilite, 408
Polydymite, 296
Polyhalite, 535
Polylithionite, 467
Polymignite, 493
Polysphærite, 499
Poonahlite, *v.* Scolecite
Porpezite, 276
Posepnyte, 544
Potash alum, 520
Potassium borate, 520
  chloride, 318, 323
  nitrate, 517
  silicate, 370, 373, 381, 464, *etc.*
  sulphate, 523
Potstone, 479
Powellite, 541
Prase, 326
Praseolite, 408
Prehnite, 442
Příbramite, 291
Priceite, 520
Prismatine, 451
Prochlorite, 475
Prolectite, 443
Prosopite, 323
Protobastite, 385
Proustite, 311
Prussian blue, Native, 5[illegible]
Przibramite, 291, 349
Pseudobrookite, 343
Pseudocampylite, 499
Pseudoleucite, 382
Pseudomalachite, 505
Pseudophite, 474
Pseudosteatite, 482
Psilomelane, 352
Psittacinite, 505
Ptilolite, 453
Pucherite, 496
Puflerite, 457
Punamu, 394

Purple copper ore, 297
Puschkinite, 439
Pycnite, 432
Pyrargillite, 408
Pyrargyrite, 311
Pyreneite, 417
Pyrgom, 390
Pyrite, 300
Pyrites, Arsenical, *v.* Arsenopyrite, 303
  Capillary, 295, 303
  Cockscomb, 303
  Copper, 297
  Iron, 300, 302
  Magnetic, 296
  Radiated, 303
  Spear, 303
  Tin, 315
  White iron, 302
Pyroaurite, 352
Pyrochlore, 489
Pyrochroite, 351
Pyrolusite, 347
Pyromorphite, 499
Pyrope, 416
Pyrophanite, 337
Pyrophosphorite, 507
Pyrophyllite, 482
Pyrophysalite, 432
Pyroretinite, 544
Pyrosclerite, 476
Pyrosmalite, 424
Pyrostibite, 307
Pyrostilpnite, 312
Pyroxene, 387
PYROXENE Group, 382
Pyrrharsenite, Pyrrhoarsenite, 495
Pyrrhite, 490
Pyrrhotine, 296
Pyrrhotite, 296

Q

Quartz, 324
Quartzine, 328
Quartzite, 327
Quarz, 324
Quecksilber, Gediegen, 279
Quecksilberbranderz, 544
Quecksilberhornerz, 317
Quenstedtite, 535
Quetenite, 538
Quicksilver, 279

R

Rädelerz, 310
Raimondite, 536
Ralstonite, 323
Ramirite, 505
Rammelsbergite, 304
Ranite, 463
Raspite, 541
Rathite, 309
Rauchquarz, *v.* Smoky Quartz, 326
Raumite, 408
Realgar, 282
Red antimony, *v.* Kermesite
  chalk, 335
  copper ore, 331
  hematite, 334
  iron ore, 335
  lead ore, 529
  ocher, 335
  silver ore, 311
  zinc ore, 332
Reddingite, 508
Reddle, 335
Redingtonite, 537
Redruthite, 290
Reinite, 542
Reissite, 454
Remingtonite, 367
Rensselaerite, 479
Resin, Mineral, 543
  Highgate,
Retinalite, 477
Retinite, 543
Retzbanyite, 307
Retzian, 507
Rezbanyite, 307
Rhabdophane, 509
Rhabdophanite, 509
Rhætizite, 434
Rhagite, 515
Rhodalose, *v.* Bieberite
Rhodizite, 519
Rhodochrome, 474
Rhodochrosite, 359
Rhodolite, 416
Rhodonite, 395
Rhodophyllite, 474
Rhodotilite, 452
Rhyacolite, 372
Riband jasper, 327
Richellite, 514
Richterite, 401
Riebeckite, 404
Rinkite, 487
Ripidolite, 473, 475
Rittingerite, 312
Rock crystal, 325
  meal, 356
  milk, 356
  salt, 318
Roeblingite, 408
Roemerite, 536
Roepperite, 422
Romanzovite, 418
Romeite, Romeine, 516
Römerite, 536
Roscoelite, 470
Rose quartz, 326
Roselite, 507
Rosenbuschite, 395
Rosite, 466
Rothbleierz, 529
Rotheisenerz, Rotheisenstein, 335
Rothgültigerz, 311
Rothkupfererz, 313
Rothnickelkies, 295
Rothoffite, 417
Rothspiessglanzerz, 305
Rothzinkerz, 332
Rowlandite, 437
Rubellite, 448
Rubicelle, 338
Rubin, 338
Ruby, Almandine, 338
  Balas, 338
  Oriental, 333
  Spinel, 338
Ruby blende, 291
Ruby copper, 313
Ruby silver, 311
Ruby spinel, 338
Ruby zinc, 291
Ruin marble, 356
Rumänite, 543
Rumpfite, 476
Ruthenium sulphide, 302
Rutile, 345

S

Safflorite, 304
Sagenite, 326, 345
Sahlite, 389
Sal Ammoniac, 319
Salite, 389
Salmiak, 319
Salmite, 472
Salt, Rock, 318
Saltpeter, *v.* Niter
Salvadorite, 534
Samarskite, 492
Sammetblende, 349
Sandbergerite, 313
Sanguinite, 312
Sanidine, 372
Saphir d'eau, 408
Saponite, 480
Sapphire, 333
Sapphirine, 451
Sarcolite, 426
Sard, 326
Sardonyx, 327
Sarkinite, 502
Sartorite, 308
Sassolite, Sassolin, 352
Satin spar, 355, 532
Saualpite, 438
Saussurite, 438
Scacchite, 321
Scapolite, Common, 425
SCAPOLITE Group, 424
Schalenblende, 291
Schapbachite, 309
Schaumerde, 355

Schaumspath, 355
Scheelbleispath, *v.* Stolzite
Scheelite, 540
Scheelspath, *v.* Scheelite
Scheererite, 543
Schefferite, 389
Schiller-spar, Schillerspath, 386
Schirmerite, 308
Schlangenalabaster, 528
Schmirgel, 333
Schneiderite, 457
Schoenite, 535
Schönite, 535
Schorlomite, 419
Schorza, 439
Schreibersite, 281
Schrifterz, Schrifttellur, 304
Schrötterite, 483
Schungite, 278
Schuppenstein, 467
Schwartzembergite, 322
Schwatzite, 313
Schwefel *v.* Sulphur, 273
Schwefelkies, 300
Schwefelquecksilber, 298
Schwerbleierz *v.* Plattnerite
Schwerspath, 524
Scleroclase, 308
Scolecite, Scolezite, 462
Scorodite, 509
Scorza, 439
Scoviilite, 509
Seebachite, 458
SELENIDES, 288, 289
Selenite, 532
SELENITES, 538
Selenium, 271
Selenquecksilber, 292
Selensulphur, 274
Selenwismuthglanz, 284
Sellaite, 321
Séméline, 486
Semi-opal, 329
Semseyite, 309
Senarmontite, 330
Sepiolite, 480
Sericite, 465
Serpentine, 476
Serpierite, 536
Seybertite, 471
Shepardite, 382
Shell marble, 356
Siberite, 448
Siderite, 359
Sideronatrite, 537
Siderophyllite, 468
Siegenite, 297
Silber, *v.* Silver, 278
Silberamalgam, 279
Silberglanz, 288
Silberhornerz, 319
Silex, Silica 324
SILICATES, 368
Siliceous sinter, 329
Silicified wood, 327
Silicon oxide, 324, 328, 329
Sillimanite, 438
Silver, Native, 278
Silver antimonide, 286
  arsenide, 286
  bismuthide, 286
  bromide, 319
  chlorides, 319
  iodide, 319
  selenide, 288
  sulphantimonites, 308, 311
  sulpharsenite, 311
  sulphide, 288, 290
  sulpho-bismuthite, 308
  sulpho-germanate, 316
  telluride, 286, 289, 305
Silver glance, 288
Simetite, 543
Simonyite, 535
Sinter, Siliceous, 329
Sipylite, 490
Siserskite, 280
Sismondine, Sismondite, 472
Sisserskite, 280
Skapolith, 425
Skleroklas, 308
Skogbölite, 492
Skutterudite, 302
Smaltite, Smaltine, 301
Smaragd, *v.* Emerald
Smaragdite, 401
Smectite, 482
Smegmatite, 482
Smirgel, 333
Smithsonite, 360; 446
Smoky quartz, 326
Soapstone, 479
Soda alum, 535
Soda microcline, 373
Soda niter, 517,
Soda orthoclase, 372
Sodalite, 412
Sodium borate, 520
  carbonate, 366, 367
  chloride, 318
  fluoride, 321, *etc.*
  nitrate, 417
  phosphate, 496, *etc.*
  silicate, 412, 460, 461
  sulphate, 523; hydrous, 531, *etc.*
Sonnenstein, *v.* Sunstone, 378
Spadaite, 480
Spangolite, 530
Spargelstein, *v.* Asparagus stone
Spathic iron, 359
Spatheisenstein, *v.* Siderite
Spear pyrites, 303
Speckstein, 479
Specular iron, 335
Speerkies, 303
Speiskobalt, 301
Spessartine, Spessartite, 417
Sperrylite, 302
Sphærite, 513
Sphærocobaltite, 361
Sphalerite, 291
Sphene, 485
Spiauterite, *v.* Wurtzite, 295
Spinel, 338
Spinel ruby, 338
Spinthère, 486
Spodiosite, 502
Spodumene, 393
Spreustein, 461
Sprödglanzerz, 314
Sprödglaserz, 314
Sprödglimmer, 470
Sprudelstein, 361
Staffelite, 499
Stalactite, 356
Stalagmite, 356
Stannite, Stannine, 315
Stassfurtite, 519
Star-quartz, 326
  sapphire, 338
Staurolite, 450
Staurotide, 450
Steatite, 479
Steenstrupine, 407
Steinheilite, 408
Steinkohle, 546
Steinmannite, 288
Steinmark, *v.* Lithomarge, 481
Steinöl, 544
Steinsalz, 318
Stephanite, 314
Stercorite, 510
Sternbergite, 290
Stibiconite, 330
Stibnite, 283
Stilbite, 456; 454
Stilpnomelane, 476
Stolpenite, 482
Stolzite, 541
Strahlerz, *v.* Clinoclasite
Strahlkies, 303
Strahlstein, 400
Stratopeite, 396
Stream tin, 344
Strengite, 510
Strigovite, 476
Stromeyerite, 290
Strontianite, 362
Strontianocalcite, 356
Strontium carbonate, 362
  silicate, 454
  sulphate, 526
Struvite, 507
Stützite, 286
Stylotypite, 310
Succinic acid, 543
Succinite, 543; 416
Sulfoborite, 521
SULPHANTIMONATES, 315

SULPHANTIMONITES, 305
SULPHARSENATES, 315
SULPHARSENITES, 305
SULPHATES, 526
SULPHIDES, 286
SULPHOBISMUTITES, 306
Sulphohalite, 530
SULPHOSTANNATES, 315
Sulphur, 273
Sundtite, 299
Sunstone, 378
Susannite, 530
Sussexite, 518
Svabite, 501
Svanbergite, 516
Sychnodymite, 306
Sylvanite, 294
Sylvite, Sylvine, 318
Symplesite, 506
Synadelphite, 508
Syngenite, 534
Syntagmatite, 400
Szaboite, 396
Szaibelyite, 518
Szmikite, 531

T

Tabasheer, 1
Tabular spar, 394
Tachhydrite, 326
Tachyhydrite, Tachydrite, 326
Taenite, 281
Tafelspath, 394
Tagilite, 511
Talc, 479
Talkeisenerz, 340
Talktriplite, 502
Tallingite, 323
Tallow, Mineral, 543
TANTALATES, 489
Tantalite, 490
Tapalpite, 310
Tapiolite, 492
Tarnowitzite, 361
Tasmanite, 544
Tavistockite, 506
Taylorite, 523
Tellur, 275
TELLURATES, 538
Tellurbismuth, 284
Tellurblei, v. Altaite, 288
Telluric wismuth, 284
TELLURIDES, 288 *et seq.*
Tellurite, 330
TELLURITES, 538
Tellurium, 275
Tellurium oxide, 330
Tellurnickel, 297
Tellursilber, v. Hessite, 289
Tellurwismuth, 284
Tengerite, 367
Tennantite, 313
Tenorite, 333
Tephroite, 428
Teschemacherite, 364
Tesseralkies, v. Skutterudite, 303
Tetradymite, 284
Tetrahedrite, 312
Thalite, 420
Thallium selenide, 289
Thaumasite, 528
Thenardite, 520
Thermonatrite, 366
Thermophyllite, 478
Thinolite, 357
Thiorsauite, 380
Thomsenolite, 328
Thomsonite, 458
Thonerde, v. Aluminium
Thorite, 488
Thorium silicate, 486, 487
Thorogummite, 488
Thulite, 438
Thuringite, 475
Tiemannite, 288
Tiger-eye, 336, 404
Tilasite, 506
Tile ore, 331
Tilkerodite, 288
Tin, Native, 279
Tin borate, 518
  oxide, 344
  sulphide, 315
Tin ore, Tin stone, 344
Tin pyrites, 315
Tincal, 520
Tinkal, 520
Tirolite, 511
TITANATES, 485
Titaneisen, 336
Titanic iron ore, 336
Titanite, 485
Titanium oxide, 345, 346, 347
Titanomorphite, 486
Topaz, 431
  False, 326
  Oriental, 333
Topazolite, 417
Torbanite, 546
Torbernite, 515
Touchstone, 327
Tourmaline, 447
Traversellite, 389
Travertine, 356
Tremolite, 400
Trichalcite, 508
Tridymite, 328
Trimerite, 424
Triphane, 398
Triphyline, 496
Triphylite, 496
Triplite, 502
Triploidite, 502
Tripolite, 329
Trippkeite, 516
Tripuhyite, 516
Tritochorite, 505
Tritomite, 497
Trögerite, 515
Troilite, 293
Trolleite, 513
Trona, 367
Troostite, 436
Tscheffkinite, Tschewkinit, 497
Tschermigite, 525
Tufa, Calcareous, 356
Tungsten trioxide, 356
Tungstite, 350
Turgite, 359
Türkis, 512
Turmalin, 447
Turnerite, 490
Turquois, Turquoise, 512
Tyrite, 490
Tyrolite, 511
Tysonite, 321

U

Uintahite, Uintaite, 545
Ulexite, 520
Ullmannite, 303
Ultramarine, 413
Umangite, 290
Unionite, 438
Uraconise, Uraconite, 538
Uralite, 401
URANATES, 521
Uraninite, 521
Uranite, 515
Uranium arsenate, 515
  carbonates, 367
  niobates, 492, 493
  phosphates, 515
  silicates, 483
  sulphate, 538
Uranmica, 515
Uranocircite, 515
Uranoniobite, 521
Uranophane, 483
Uranopilite, 538
Uranosphærite, 523
Uranospinite, 515
Uranothallite, 367
Uranotil, 483
Uranpecherz, 521
Urao, 367
Urbanite, 389
Urpethite, 543
Urusite, 537
Utahite, 536
Uvarovite, Uwarowit, 417

V

Vaalite, 476
Valencianite, 372
Valentinite, 330

Vanadinbleierz, *v.* Vanadinite
Vanadinite, 500
Vanadium silicate, 470
Variegated copper ore, 297
Variscite, 510
Vauquelinite, 529
Velvet copper ore, *v.* Lettsomite
Venus-hairstone, 345
Verd-antique, 477
VERMICULITES, 476
Vermilion, *v.* Cinnabar
Vesuvianite, 427
Veszelyite, 511
Viluite, 428
Violan, 389
Vitreous copper, *v.* Chalcocite
    silver, *v.* Argentite
Vitriol, Blue, *etc.*
Vitriolbleierz, 527
Vivianite, 508
Voglianite, 538
Voglite, 367
Volborthite, 511
Voltaite, 537
Voltzite, Voltzine, 305
Vulpinite, 528

W

Wad, 352
Wagnerite, 502
Walkerite, 395
Walpurgite, 515
Waluewite, 471
Wapplerite, 510
Wardite, 512
Waringtonite, 530
Warrenite, 308
Warringtonite, 530
Warwickite, 519
Washingtonite, 337
Wassersapphir, *v.* Iolite
Wavellite, 512
Webnerite, 308
Websterite, 537
Wehrlite, 285
Weissbleierz, 363
Weissgültigerz, 318
Wellsite, 455
Wernerite, 425
Wheel ore, 310
Whewellite, 542
White antimony, 330
White arsenic, 330
    garnet, *v.* Leucite
    iron pyrites, 302
    lead ore, 363
Whitneyite, 286
Willemite, 422
Willyamite, 302
Wilsonite, 466
Wiluite, 428
Wiserine, 347
Wismuth, *v.* Bismuth
Wismuthantimonnickelglanz, 302
Wismuthblende, 414
Wismuthglanz, 284
Wismuthspath, 367
Withamite, 439
Witherite, 362
Wittichenite, 310
Wocheinite, 351
Wöhlerite, 395
Wolfachite, 304
Wolfram, 539
Wolframite, 539
Wolfsbergite, 308
Wollastonite, 394
Wolnyn, 525
Wood, Fossil, Petrified, 327
Wood copper, 504
Wood opal, 329
Wood tin, 344
Wörthite, 434
Wulfenite, 541
Würfelerz, *v.* Pharmacosiderite
Wurtzite, 295

X

Xantharsenite, 505
Xanthoconite, 315
Xanthophyllite, 471
Xanthosiderite, 350
Xenolite, 434
Xenotime, 494

Y

Yellow copper ore, 297
    lead ore, 541
Yenite, 445
Yttergranat, 417
Yttrialite, 437
Yttrium carbonate, 367
Yttrium niobates, 490, *etc.*
    phosphates, 494, 509
    silicates, 437
Yttrocerite, 323
Yttrocolumbite, *v.* Yttrotantalite, 492
Yttrogummite, 522
Yttrotantalite, 492

Z

Zaratite, 367
ZEOLITES, 453
Zepharovichite, 510
Zeunerite, 515
Zeigelerz, 331
Zietrisikite, 543
Zinc, Native, 275
    Red Oxide of, 332
Zinc aluminate, 339
    arsenates, 505, 509
    carbonates, 360
    oxide, 332, 339
    oxysulphide, 305
    phosphate, 507
    silicates, 422, 446, 447
    sulphates, 528, 533
    sulphides, 291, 295
    vanadate, 505
Zinc blende, 291
Zinc ore, Red, 332
Zincaluminite, 538
Zincite, 332
Zinckenite, 307
Zincocalcite, 356
Zinkblende, 291
Zinkenite, 307
Zinkosite, 528
Zinkspath, 360
Zinnerz, 344
Zinnkies, 315
Zinnober, 293
Zinnstein, 344
Zinnwaldite, 467
Zippeite, 538
Zircon, 429
Zirconium dioxide, 346
    silicate, 429; 395
Zirkelite, 346
Zoisite, 437
Zorgite, 289
Zunyite, 414
Zwieselite, 502

SHORT-TITLE CATALOGUE

OF THE

PUBLICATIONS

OF

JOHN WILEY & SONS,

NEW YORK.

LONDON: CHAPMAN & HALL, LIMITED.

ARRANGED UNDER SUBJECTS.

Descriptive circulars sent on application.
Books marked with an asterisk are sold at *net* prices only.
All books are bound in cloth unless otherwise stated.

AGRICULTURE.

CATTLE FEEDING—DAIRY PRACTICE—DISEASES OF ANIMALS—GARDENING, ETC.

Armsby's Manual of Cattle Feeding	12mo,	$1 75
Downing's Fruit and Fruit Trees	8vo,	5 00
Grotenfelt's The Principles of Modern Dairy Practice. (Woll.)	12mo,	2 00
Kemp's Landscape Gardening	12mo,	2 50
Loudon's Gardening for Ladies. (Downing.)	12mo,	1 50
Maynard's Landscape Gardening	12mo,	1 50
Steel's Treatise on the Diseases of the Dog	8vo,	3 50
" Treatise on the Diseases of the Ox	8vo,	6 00
Stockbridge's Rocks and Soils	8vo,	2 50
Woll's Handbook for Farmers and Dairymen	12mo,	1 50

ARCHITECTURE.

BUILDING—CARPENTRY—STAIRS—VENTILATION—LAW, ETC.

Berg's Buildings and Structures of American Railroads	4to,	7 50
Birkmire's American Theatres—Planning and Construction.	8vo,	3 00
" Architectural Iron and Steel	8vo,	3 50
" Compound Riveted Girders	8vo,	2 00
" Skeleton Construction in Buildings	8vo,	3 00

Birkmire's Planning and Construction of High Office Buildings.	8vo,	$3 50
Carpenter's Heating and Ventilating of Buildings	8vo,	3 00
Freitag's Architectural Engineering	8vo,	2 50
Gerhard's Sanitary House Inspection	16mo,	1 00
" Theatre Fires and Panics	12mo,	1 50
Hatfield's American House Carpenter	8vo,	5 00
Holly's Carpenter and Joiner	18mo,	75
Kidder's Architect and Builder's Pocket-book	16mo, morocco,	4 00
Merrill's Stones for Building and Decoration	8vo,	5 00
Monckton's Stair Building—Wood, Iron, and Stone	4to,	4 00
Wait's Engineering and Architectural Jurisprudence	8vo,	6 00
	Sheep,	6 50
Worcester's Small Hospitals—Establishment and Maintenance, including Atkinson's Suggestions for Hospital Architecture	12mo,	1 25
World's Columbian Exposition of 1893	Large 4to,	2 50

ARMY, NAVY, Etc.

MILITARY ENGINEERING—ORDNANCE—LAW, ETC.

Bourne's Screw Propellers	4to,	5 00
Bruff's Ordnance and Gunnery	8vo,	6 00
Chase's Screw Propellers	8vo,	3 00
Cooke's Naval Ordnance	8vo,	12 50
Cronkhite's Gunnery for Non-com. Officers	32mo, morocco,	2 00
Davis's Treatise on Military Law	8vo,	7 00
	Sheep,	7 50
" Elements of Law	8vo,	2 50
De Brack's Cavalry Outpost Duties. (Carr.)	32mo, morocco,	2 00
Dietz's Soldier's First Aid	16mo, morocco,	1 25
* Dredge's Modern French Artillery	Lagre 4to, half morocco,	15 00
" Record of the Transportation Exhibits Building, World's Columbian Exposition of 1893	4to, half morocco,	10 00
Durand's Resistance and Propulsion of Ships	8vo,	5 00
Dyer's Light Artillery	12mo,	3 00
Hoff's Naval Tactics	8vo,	1 50
Ingalls's Ballistic Tables	8vo,	1 50
" Handbook of Problems in Direct Fire	8vo,	4 00

Mahan's Advanced Guard	18mo,	$1 50
" Permanent Fortifications. (Mercur.).	8vo, half morocco,	7 50
Mercur's Attack of Fortified Places	12mo,	2 00
" Elements of the Art of War	8vo,	4 00
Metcalfe's Ordnance and Gunnery	12mo, with Atlas,	5 00
Murray's A Manual for Courts-Martial	16mo, morocco,	1 50
" Infantry Drill Regulations adapted to the Springfield Rifle, Caliber .45	32mo, paper,	10
Phelps's Practical Marine Surveying	8vo,	2 50
Powell's Army Officer's Examiner	12mo,	4 00
Sharpe's Subsisting Armies	32mo, morocco,	1 50
Very's Navies of the World	8vo, half morocco,	3 50
Wheeler's Siege Operations	8vo,	2 00
Winthrop's Abridgment of Military Law	12mo,	2 50
Woodhull's Notes on Military Hygiene	16mo,	1 50
Young's Simple Elements of Navigation	16mo, morocco flaps,	2 00
" " " " "	first edition	1 00

ASSAYING.

Smelting—Ore Dressing—Alloys, Etc.

Fletcher's Quant. Assaying with the Blowpipe	16mo, morocco,	1 50
Furman's Practical Assaying	8vo,	3 00
Kunhardt's Ore Dressing	8vo,	1 50
O'Driscoll's Treatment of Gold Ores	8vo,	2 00
Ricketts and Miller's Notes on Assaying	8vo,	3 00
Thurston's Alloys, Brasses, and Bronzes	8vo,	2 50
Wilson's Cyanide Processes	12mo,	1 50
" The Chlorination Process	12mo,	1 50

ASTRONOMY.

Practical, Theoretical, and Descriptive.

Craig's Azimuth	4to,	3 50
Doolittle's Practical Astronomy	8vo,	4 00
Gore's Elements of Geodesy	8vo,	2 50
Hayford's Text-book of Geodetic Astronomy	8vo.	3 00
Michie and Harlow's Practical Astronomy	8vo,	3 00
White's Theoretical and Descriptive Astronomy	12mo,	2 00

BOTANY.

Gardening for Ladies, Etc.

Baldwin's Orchids of New England	Small 8vo,	$1 50
Loudon's Gardening for Ladies. (Downing.)	12mo,	1 50
Thomé's Structural Botany	16mo,	2 25
Westermaier's General Botany. (Schneider.)	8vo,	2 00

BRIDGES, ROOFS, Etc.

Cantilever—Draw—Highway—Suspension.

(See also Engineering, p. 7.)

Boller's Highway Bridges	8vo,	2 00
* " The Thames River Bridge	4to, paper,	5 00
Burr's Stresses in Bridges	8vo,	3 50
Crehore's Mechanics of the Girder	8vo,	5 00
Dredge's Thames Bridges	7 parts, per part,	1 25
Du Bois's Stresses in Framed Structures	Small 4to,	10 50
Foster's Wooden Trestle Bridges	4to,	5 00
Greene's Arches in Wood, etc.	8vo,	2 50
" Bridge Trusses	8vo,	2 00
" Roof Trusses	8vo,	1 25
Howe's Treatise on Arches	8vo,	4 00
Johnson's Modern Framed Structures	Small 4to,	10 00
Merriman & Jacoby's Text-book of Roofs and Bridges. Part I., Stresses	8vo,	2 50
Merriman & Jacoby's Text-book of Roofs and Bridges. Part II., Graphic Statics	8vo.	2 50
Merriman & Jacoby's Text-book of Roofs and Bridges. Part III., Bridge Design	8vo,	2 50
Merriman & Jacoby's Text-book of Roofs and Bridges. Part IV., Continuous, Draw, Cantilever, Suspension, and Arched Bridges	8vo,	2 50
* Morison's The Memphis Bridge	Oblong 4to,	10 00
Waddell's Iron Highway Bridges	8vo,	4 00
" De Pontibus (a Pocket-book for Bridge Engineers).	16mo, morocco,	3 00
Wood's Construction of Bridges and Roofs	8vo,	2 00
Wright's Designing of Draw Spans. Parts I. and II.	8vo, each	2 50
" " " " " Complete	8vo,	3 50

CHEMISTRY.

QUALITATIVE—QUANTITATIVE—ORGANIC—INORGANIC, ETC.

Adriance's Laboratory Calculations	12mo,	$1 25
Allen's Tables for Iron Analysis	8vo,	3 00
Austen's Notes for Chemical Students	12mo,	1 50
Bolton's Student's Guide in Quantitative Analysis	8vo,	1 50
Classen's Analysis by Electrolysis. (Herrick and Boltwood.)	8vo,	3 00
Crafts's Qualitative Analysis. (Schaeffer.)	12mo,	1 50
Drechsel's Chemical Reactions. (Merrill.)	12mo,	1 25
Fresenius's Quantitative Chemical Analysis. (Allen.)	8vo,	6 00
" Qualitative " " (Johnson.)	8vo,	3 00
" " " " (Wells.) Trans. 16th German Edition	8vo,	5 00
Fuertes's Water and Public Health	12mo,	1 50
Gill's Gas and Fuel Analysis	12mo,	1 25
Hammarsten's Physiological Chemistry. (Mandel.)	8vo,	4 00
Helm's Principles of Mathematical Chemistry. (Morgan).	12mo,	1 50
Kolbe's Inorganic Chemistry	12mo,	1 50
Ladd's Quantitative Chemical Analysis	12mo,	1 00
Landauer's Spectrum Analysis. (Tingle.)	8vo,	3 00
Löb's Electrolysis and Electrosynthesis of Organic Compounds. (Lorenz.)	12mo,	1 00
Mandel's Bio-chemical Laboratory	12mo,	1 50
Mason's Water-supply	8vo,	5 00
" Examination of Water. *(In the press.)*		
Miller's Chemical Physics	8vo,	2 00
Mixter's Elementary Text-book of Chemistry	12mo,	1 50
Morgan's The Theory of Solutions and its Results	12mo,	1 00
Nichols's Water-supply (Chemical and Sanitary)	8vo,	2 50
O'Brine's Laboratory Guide to Chemical Analysis	8vo,	2 00
Perkins's Qualitative Analysis	12mo,	1 00
Pinner's Organic Chemistry. (Austen.)	12mo,	1 50
Poole's Calorific Power of Fuels	8vo,	3 00
Ricketts and Russell's Notes on Inorganic Chemistry (Non-metallic)	Oblong 8vo, morocco,	75
Ruddiman's Incompatibilities in Prescriptions	8vo,	2 00
Schimpf's Volumetric Analysis	12mo,	2 50
Spencer's Sugar Manufacturer's Handbook.	16mo, morocco flaps,	2 00

Spencer's Handbook for Chemists of Beet Sugar Houses.	16mo, morocco,	$3 00
Stockbridge's Rocks and Soils	8vo,	2 50
Van Deventer's Physical Chemistry for Beginners. (Boltwood.)	12mo,	
Wells's Inorganic Qualitative Analysis	12mo,	1 50
" Laboratory Guide in Qualitative Chemical Analysis.	8vo,	1 50
Whipple's Microscopy of Drinking-water	8vo,	
Wiechmann's Chemical Lecture Notes	12mo,	3 00
" Sugar Analysis	Small 8vo,	2 50
Wulling's Inorganic Phar. and Med. Chemistry	12mo,	2 00

DRAWING.

ELEMENTARY—GEOMETRICAL—MECHANICAL—TOPOGRAPHICAL.

Hill's Shades and Shadows and Perspective	8vo,	2 00
MacCord's Descriptive Geometry	8vo,	3 00
" Kinematics	8vo,	5 00
" Mechanical Drawing	8vo,	4 00
Mahan's Industrial Drawing. (Thompson.)	2 vols., 8vo,	3 50
Reed's Topographical Drawing. (H. A.)	4to,	5 00
Reid's A Course in Mechanical Drawing	8vo.	2 00
" Mechanical Drawing and Elementary Machine Design.	8vo. (*In the press.*)	
Smith's Topographical Drawing. (Macmillan.)	8vo,	2 50
Warren's Descriptive Geometry	2 vols., 8vo,	3 50
" Drafting Instruments	12mo,	1 25
" Free-hand Drawing	12mo,	1 00
" Linear Perspective	12mo,	1 00
" Machine Construction	2 vols., 8vo,	7 50
" Plane Problems	12mo,	1 25
" Primary Geometry	12mo,	75
" Problems and Theorems	8vo,	2 50
" Projection Drawing	12mo,	1 50
" Shades and Shadows	8vo.	3 00
" Stereotomy—Stone-cutting	8vo,	2 50
Whelpley's Letter Engraving	12mo,	2 00

ELECTRICITY AND MAGNETISM.

ILLUMINATION—BATTERIES—PHYSICS.

Anthony and Brackett's Text-book of Physics. (Magie.)..8vo,	$3 00
Anthony's Theory of Electrical Measurements...........12mo,	1 00
Barker's Deep-sea Soundings.............................8vo,	2 00
Benjamin's Voltaic Cell.................................8vo,	3 00
" History of Electricity..........................8vo	3 00
Cosmic Law of Thermal Repulsion.....................12mo,	75
Crehore and Squier's Experiments with a New Polarizing Photo-Chronograph.....................................8vo,	3 00
* Dredge's Electric Illuminations....2 vols., 4to, half morocco,	25 00
" " " Vol. II...................4to,	7 50
Gilbert's De magnete. (Mottelay.).......................8vo,	2 50
Holman's Precision of Measurements.....................8vo,	2 00
" Telescope-mirror-scale Method............Large 8vo,	75
Michie's Wave Motion Relating to Sound and Light,.......8vo,	4 00
Morgan's The Theory of Solutions and its Results........12mo,	1 00
Niaudet's Electric Batteries. (Fishback.)...............12mo,	2 50
Pratt and Alden's Street-railway Road-beds..............8vo,	2 00
Reagan's Steam and Electric Locomotives...............12mo,	2 00
Thurston's Stationary Steam Engines for Electric Lighting Purposes...12mo,	
Tillman's Heat...8vo,	1 50

ENGINEERING.

CIVIL—MECHANICAL—SANITARY, ETC.

(*See also* BRIDGES, p. 4; HYDRAULICS, p. 9; MATERIALS OF ENGINEERING, p. 10; MECHANICS AND MACHINERY, p. 12; STEAM ENGINES AND BOILERS, p. 14.)

Baker's Masonry Construction...........................8vo,	5 00
" Surveying Instruments........................12mo,	3 00
Black's U. S. Public Works.....................Oblong 4to,	5 00
Brooks's Street-railway Location...............16mo, morocco,	1 50
Byrne's Highway Construction...........................8vo,	5 00
" Inspection of Materials and Workmanship.......16mo,	3 00
Carpenter's Experimental Engineering 8vo,	6 00

Church's Mechanics of Engineering—Solids and Fluids	8vo,	$6 00
" Notes and Examples in Mechanics	8vo,	2 00
Crandall's Earthwork Tables	8vo,	1 50
" The Transition Curve	16mo, morocco,	1 50
*Dredge's Penn. Railroad Construction, etc.	Folio, half mor.,	20 00
*Drinker's Tunnelling	4to, half morocco,	25 00
Eissler's Explosives—Nitroglycerine and Dynamite	8vo,	4 00
Folwell's Sewerage	8vo,	3 00
Fowler's Coffer-dam Process for Piers	8vo,	2 50
Gerhard's Sanitary House Inspection	12mo,	1 00
Godwin's Railroad Engineer's Field-book	16mo, morocco,	2 50
Gore's Elements of Geodesy	8vo,	2 50
Howard's Transition Curve Field-book	12mo, morocco flap,	1 50
Howe's Retaining Walls (New Edition.)	12mo,	1 25
Hudson's Excavation Tables. Vol. II	8vo,	1 00
Hutton's Mechanical Engineering of Power Plants	8vo,	5 00
Johnson's Materials of Construction	Large 8vo,	6 00
" Stadia Reduction Diagram	Sheet, 22½ × 28½ inches,	50
" Theory and Practice of Surveying	Small 8vo,	4 00
Kent's Mechanical Engineer's Pocket-book	16mo, morocco,	5 00
Kiersted's Sewage Disposal	12mo,	1 25
Mahan's Civil Engineering. (Wood.)	8vo,	5 00
Merriman and Brook's Handbook for Surveyors	16mo, mor.,	2 00
Merriman's Geodetic Surveying	8vo,	2 00
" Retaining Walls and Masonry Dams	8vo,	2 00
" Sanitary Engineering	8vo,	2 00
Nagle's Manual for Railroad Engineers	16mo, morocco,	3 00
Patton's Civil Engineering	8vo,	7 50
" Foundations	8vo,	5 00
Pratt and Alden's Street-railway Road-beds	8vo,	2 00
Rockwell's Roads and Pavements in France	12mo,	1 25
Ruffner's Non-tidal Rivers	8vo,	1 25
Searles's Field Engineering	16mo, morocco flaps,	3 00
" Railroad Spiral	16mo, morocco flaps,	1 50
Siebert and Biggin's Modern Stone Cutting and Masonry	8vo,	1 50
Smart's Engineering Laboratory Practice	12mo,	2 50
Smith's Wire Manufacture and Uses	Small 4to,	3 00
Spalding's Roads and Pavements	12mo,	2 00

Spalding's Hydraulic Cement	12mo,	$2 00
Taylor's Prismoidal Formulas and Earthwork	8vo,	1 50
Thurston's Materials of Construction	8vo,	5 00
* Trautwine's Civil Engineer's Pocket-book	16mo, mor. flaps,	5 00
* " Cross-section	Sheet,	25
* " Excavations and Embankments	8vo,	2 00
* " Laying Out Curves	12mo, morocco,	2 50
Waddell's De Pontibus (A Pocket-book for Bridge Engineers).	16mo, morocco,	3 00
Wait's Engineering and Architectural Jurisprudence	8vo,	6 00
	Sheep,	6 50
" Law of Field Operation in Engineering, etc.	8vo.	
Warren's Stereotomy—Stone-cutting	8vo,	2 50
Webb's Engineering Instruments	16mo, morocco,	1 00
Wegmann's Construction of Masonry Dams	4to,	5 00
Wellington's Location of Railways	8vo,	5 00
Wheeler's Civil Engineering	8vo,	4 00
Wolff's Windmill as a Prime Mover	8vo,	3 00

HYDRAULICS.

WATER-WHEELS—WINDMILLS—SERVICE PIPE—DRAINAGE, ETC.

(*See also* ENGINEERING, p. 7.)

Bazin's Experiments upon the Contraction of the Liquid Vein. (Trautwine.)	8vo,	2 00
Bovey's Treatise on Hydraulics	8vo,	4 00
Coffin's Graphical Solution of Hydraulic Problems	12mo,	2 50
Ferrel's Treatise on the Winds, Cyclones, and Tornadoes	8vo,	4 00
Fuertes's Water and Public Health	12mo,	1 50
Ganguillet & Kutter's Flow of Water. (Hering & Trautwine.)	8vo,	4 00
Hazen's Filtration of Public Water Supply	8vo,	2 00
Herschel's 115 Experiments	8vo,	2 00
Kiersted's Sewage Disposal	12mo,	1 25
Mason's Water Supply	8vo,	5 00
Merriman's Treatise on Hydraulics	8vo,	4 00
Nichols's Water Supply (Chemical and Sanitary)	8vo,	2 50
Ruffner's Improvement for Non-tidal Rivers	8vo,	1 25
Wegmann's Water Supply of the City of New York	4to,	10 00
Weisbach's Hydraulics. (Du Bois.)	8vo,	5 00
Wilson's Irrigation Engineering	8vo,	4 00
" Hydraulic and Placer Mining	12mo,	2 00
Wolff's Windmill as a Prime Mover	8vo,	3 00
Wood's Theory of Turbines	8vo,	2 50

MANUFACTURES.

BOILERS—EXPLOSIVES—IRON—SUGAR—WATCHES—WOOLLENS, ETC.

Allen's Tables for Iron Analysis	**8vo,**	**$3 00**
Beaumont's Woollen and Worsted Manufacture	**12mo,**	**1 50**
Bolland's Encyclopædia of Founding Terms	**12mo,**	**3 00**
" The Iron Founder	**12mo,**	**2 50**
" " " " Supplement	**12mo,**	**2 50**
Bouvier's Handbook on Oil Painting	**12mo,**	**2 00**
Eissler's Explosives, Nitroglycerine and Dynamite	**8vo,**	**4 00**
Ford's Boiler Making for Boiler Makers	**18mo,**	**1 00**
Metcalfe's Cost of Manufactures	**8vo,**	**5 00**
Metcalf's Steel—A Manual for Steel Users	**12mo,**	**2 00**
*** Reisig's Guide to Piece Dyeing**	**8vo,**	**25 00**
Spencer's Sugar Manufacturer's Handbook	**16mo, mor. flap,**	**2 00**
" Handbook for Chemists of Beet Sugar Houses.	**16mo, mor. flap,**	**3 00**
Thurston's Manual of Steam Boilers	**8vo,**	**5 00**
Walke's Lectures on Explosives	**8vo,**	**4 00**
West's American Foundry Practice	**12mo,**	**2 50**
" Moulder's Text-book	**12mo,**	**2 50**
Wiechmann's Sugar Analysis	**Small 8vo,**	**2 50**
Woodbury's Fire Protection of Mills	**8vo,**	**2 50**

MATERIALS OF ENGINEERING.

STRENGTH—ELASTICITY—RESISTANCE, ETC.

(*See also* ENGINEERING, p. 7.)

Baker's Masonry Construction	8vo,	5 00
Beardslee and Kent's Strength of Wrought Iron	8vo,	1 50
Bovey's Strength of Materials	8vo,	7 50
Burr's Elasticity and Resistance of Materials	8vo,	5 00
Byrne's Highway Construction	8vo,	5 00
Church's Mechanics of Engineering—Solids and Fluids	8vo,	6 00
Du Bois's Stresses in Framed Structures	Small 4to,	10 00
Johnson's Materials of Construction	8vo,	6 00
Lanza's Applied Mechanics	8vo,	7 50
Martens's Materials. (Henning.)	8vo.	(*In the press.*)
Merrill's Stones for Building and Decoration	8vo,	5 00
Merriman's Mechanics of Materials	8vo,	4 00
" Strength of Materials	12mo,	1 00
Patton's Treatise on Foundations	8vo,	5 00
Rockwell's Roads and Pavements in France	12mo,	1 25
Spalding's Roads and Pavements	12mo,	2 00

Thurston's Materials of Construction	8vo,	$5 00
" Materials of Engineering	3 vols., 8vo,	8 00
Vol. I., Non-metallic	8vo,	2 00
Vol. II., Iron and Steel	8vo,	3 50
Vol. III., Alloys, Brasses, and Bronzes	8vo,	2 50
Wood's Resistance of Materials	8vo,	2 00

MATHEMATICS.

CALCULUS—GEOMETRY—TRIGONOMETRY, ETC.

Baker's Elliptic Functions	8vo,	1 50
Ballard's Pyramid Problem	8vo,	1 50
Barnard's Pyramid Problem	8vo,	1 50
Bass's Differential Calculus	12mo,	4 00
Briggs's Plane Analytical Geometry	12mo,	1 00
Chapman's Theory of Equations	12mo,	1 50
Compton's Logarithmic Computations	12mo,	1 50
Davis's Introduction to the Logic of Algebra	8vo,	1 50
Halsted's Elements of Geometry	8vo,	1 75
" Synthetic Geometry	8vo,	1 50
Johnson's Curve Tracing	12mo,	1 00
" Differential Equations—Ordinary and Partial.	Small 8vo,	3 50
" Integral Calculus	12mo,	1 50
" " " Unabridged. 12mo. (*In the press.*)		
" Least Squares	12mo,	1 50
Ludlow's Logarithmic and Other Tables. (Bass.)	8vo,	2 00
" Trigonometry with Tables. (Bass.)	8vo,	3 00
Mahan's Descriptive Geometry (Stone Cutting)	8vo,	1 50
Merriman and Woodward's Higher Mathematics	8vo,	5 00
Merriman's Method of Least Squares	8vo,	2 00
Parker's Quadrature of the Circle	8vo,	2 50
Rice and Johnson's Differential and Integral Calculus,	2 vols. in 1, 12mo,	2 50
" Differential Calculus	Small 8vo,	3 00
" Abridgment of Differential Calculus.	Small 8vo,	1 50
Totten's Metrology	8vo,	2 50
Warren's Descriptive Geometry	2 vols., 8vo,	3 50
" Drafting Instruments	12mo,	1 25
" Free-hand Drawing	12mo,	1 00
" Higher Linear Perspective	8vo,	3 50
" Linear Perspective	12mo,	1 00
" Primary Geometry	12mo,	75
" Plane Problems	12mo,	1 25

Warren's Problems and Theorems	8vo,	$2 50
" Projection Drawing	12mo,	1 50
Wood's Co-ordinate Geometry	8vo,	2 50
" Trigonometry	12mo,	1 00
Woolf's Descriptive Geometry	Royal 8vo,	3 00

MECHANICS—MACHINERY.

TEXT-BOOKS AND PRACTICAL WORKS.

(*See also* ENGINEERING, p. 7.)

Baldwin's Steam Heating for Buildings	12mo,	2 50
Benjamin's Wrinkles and Recipes	12mo,	2 00
Chordal's Letters to Mechanics	12mo,	2 00
Church's Mechanics of Engineering	8vo,	6 00
" Notes and Examples in Mechanics	8vo,	2 00
Crehore's Mechanics of the Girder	8vo,	5 00
Cromwell's Belts and Pulleys	12mo,	1 50
" Toothed Gearing	12mo,	1 50
Compton's First Lessons in Metal Working	12mo,	1 50
Compton and De Groodt's Speed Lathe	12mo,	1 50
Dana's Elementary Mechanics	12mo,	1 50
Dingey's Machinery Pattern Making	12mo,	2 00
Dredge's Trans. Exhibits Building, World Exposition.	4to, half morocco,	10 00
Du Bois's Mechanics. Vol. I., Kinematics	8vo,	3 50
" " Vol. II., Statics	8vo,	4 00
" " Vol. III., Kinetics	8vo,	3 50
Fitzgerald's Boston Machinist	18mo,	1 00
Flather's Dynamometers	12mo,	2 00
" Rope Driving	12mo,	2 00
Hall's Car Lubrication	12mo,	1 00
Holly's Saw Filing	16mo,	75
Johnson's Theoretical Mechanics. An Elementary Treatise. (*In the press.*)		
Jones's Machine Design. Part I., Kinematics	8vo,	1 50
" " " Part II., Strength and Proportion of Machine Parts	8vo,	
Lanza's Applied Mechanics	8vo,	7 50
MacCord's Kinematics	8vo,	5 00
Merriman's Mechanics of Materials	8vo,	4 00
Metcalfe's Cost of Manufactures	8vo,	5 00
Michie's Analytical Mechanics	8vo,	4 00
Richards's Compressed Air	12mo,	1 50
Robinson's Principles of Mechanism	8vo,	3 00
Smith's Press-working of Metals	8vo,	3 00
Thurston's Friction and Lost Work	8vo,	3 00

Thurston's The Animal as a Machine 12mo,	$1 00
Warren's Machine Construction 2 vols., 8vo,	7 50
Weisbach's Hydraulics and Hydraulic Motors. (Du Bois.)..8vo,	5 00
" Mechanics of Engineering. Vol. III., Part I., Sec. I. (Klein.) 8vo,	5 00
Weisbach's Mechanics of Engineering. Vol. III., Part I., Sec. II. (Klein.) 8vo,	5 00
Weisbach's Steam Engines. (Du Bois.) 8vo,	5 00
Wood's Analytical Mechanics 8vo,	3 00
" Elementary Mechanics 12mo,	1 25
" " " Supplement and Key 12mo,	1 25

METALLURGY.

IRON—GOLD—SILVER—ALLOYS, ETC.

Allen's Tables for Iron Analysis 8vo,	3 00
Egleston's Gold and Mercury Large 8vo,	7 50
" Metallurgy of Silver Large 8vo,	7 50
* Kerl's Metallurgy—Copper and Iron 8vo,	15 00
* " " Steel, Fuel, etc 8vo,	15 00
Kunhardt's Ore Dressing in Europe 8vo,	1 50
Metcalf's Steel—A Manual for Steel Users 12mo,	2 00
O'Driscoll's Treatment of Gold Ores 8vo,	2 00
Thurston's Iron and Steel 8vo,	3 50
" Alloys 8vo,	2 50
Wilson's Cyanide Processes 12mo,	1 50

MINERALOGY AND MINING.

MINE ACCIDENTS—VENTILATION—ORE DRESSING, ETC.

Barringer's Minerals of Commercial Value....Oblong morocco,	2 50
Beard's Ventilation of Mines 12mo,	2 50
Boyd's Resources of South Western Virginia 8vo,	3 00
" Map of South Western Virginia.....Pocket-book form,	2 00
Brush and Penfield's Determinative Mineralogy. New Ed. 8vo,	4 00
Chester's Catalogue of Minerals 8vo,	1 25
" " " " Paper,	50
" Dictionary of the Names of Minerals 8vo,	3 00
Dana's American Localities of Minerals 8vo,	1 00
" Descriptive Mineralogy. (E. S.).....8vo, half morocco,	12 50
" Mineralogy and Petrography (J.D.) 12mo,	2 00
" Minerals and How to Study Them. (E. S.) 12mo,	1 50
" Text-book of Mineralogy. (E. S.)...New Edition. 8vo,	4 00
* Drinker's Tunnelling, Explosives, Compounds, and Rock Drills. 4to, half morocco,	25 00

Egleston's Catalogue of Minerals and Synonyms	8vo,	$2 50
Eissler's Explosives—Nitroglycerine and Dynamite	8vo,	4 00
Hussak's Rock-forming Minerals. (Smith.)	Small 8vo,	2 00
Ihlseng's Manual of Mining	8vo,	4 00
Kunhardt's Ore Dressing in Europe	8vo,	1 50
O'Driscoll's Treatment of Gold Ores	8vo,	2 00
* Penfield's Record of Mineral Tests	Paper, 8vo,	50
Rosenbusch's Microscopical Physiography of Minerals and Rocks. (Iddings.)	8vo,	5 00
Sawyer's Accidents in Mines	Large 8vo,	7 00
Stockbridge's Rocks and Soils	8vo,	2 50
Walke's Lectures on Explosives	8vo,	4 00
Williams's Lithology	8vo,	3 00
Wilson's Mine Ventilation	16mo,	1 25
" Hydraulic and Placer Mining	12mo,	2 50

STEAM AND ELECTRICAL ENGINES, BOILERS, Etc.

STATIONARY—MARINE—LOCOMOTIVE—GAS ENGINES, ETC.

(*See also* ENGINEERING, p. 7.)

Baldwin's Steam Heating for Buildings	12mo,	2 50
Clerk's Gas Engine	Small 8vo,	4 00
Ford's Boiler Making for Boiler Makers	18mo,	1 00
Hemenway's Indicator Practice	12mo,	2 00
Hoadley's Warm-blast Furnace	8vo,	1 50
Kneass's Practice and Theory of the Injector	8vo,	1 50
MacCord's Slide Valve	8vo,	2 00
Meyer's Modern Locomotive Construction	4to,	10 00
Peabody and Miller's Steam-boilers	8vo,	4 00
Peabody's Tables of Saturated Steam	8vo,	1 00
" Thermodynamics of the Steam Engine	8vo,	5 00
" Valve Gears for the Steam-Engine	8vo,	2 50
Pray's Twenty Years with the Indicator	Large 8vo,	2 50
Pupin and Osterberg's Thermodynamics	12mo,	1 25
Reagan's Steam and Electric Locomotives	12mo,	2 00
Röntgen's Thermodynamics. (Du Bois.)	8vo,	5 00
Sinclair's Locomotive Running	12mo,	2 00
Snow's Steam-boiler Practice	8vo. (*In the press.*)	
Thurston's Boiler Explosions	12mo,	1 50
" Engine and Boiler Trials	8vo,	5 00
" Manual of the Steam Engine. Part I., Structure and Theory	8vo,	6 00
" Manual of the Steam Engine. Part II., Design, Construction, and Operation	8vo,	6 00
	2 parts,	10 00

Thurston's Philosophy of the Steam Engine	12mo,	$ 75
" Reflection on the Motive Power of Heat. (Carnot.)	12mo,	1 50
" Stationary Steam Engines	12mo,	1 50
" Steam-boiler Construction and Operation	8vo,	5 00
Spangler's Valve Gears	8vo,	2 50
Weisbach's Steam Engine. (Du Bois.)	8vo,	5 00
Whitham's Constructive Steam Engineering	8vo,	10 00
" Steam-engine Design	8vo,	5 00
Wilson's Steam Boilers. (Flather.)	12mo,	2 50
Wood's Thermodynamics, Heat Motors, etc	8vo,	4 00

TABLES, WEIGHTS, AND MEASURES.

FOR ACTUARIES, CHEMISTS, ENGINEERS, MECHANICS—METRIC TABLES, ETC.

Adriance's Laboratory Calculations	12mo,	1 25
Allen's Tables for Iron Analysis	8vo,	3 00
Bixby's Graphical Computing Tables	Sheet,	25
Compton's Logarithms	12mo,	1 50
Crandall's Railway and Earthwork Tables	8vo,	1 50
Egleston's Weights and Measures	18mo,	75
Fisher's Table of Cubic Yards	Cardboard,	25
Hudson's Excavation Tables. Vol. II	8vo,	1 00
Johnson's Stadia and Earthwork Tables	8vo,	1 25
Ludlow's Logarithmic and Other Tables. (Bass.)	12mo,	2 00
Totten's Metrology	8vo,	2 50

VENTILATION.

STEAM HEATING—HOUSE INSPECTION—MINE VENTILATION.

Baldwin's Steam Heating	12mo,	2 50
Beard's Ventilation of Mines	12mo,	2 50
Carpenter's Heating and Ventilating of Buildings	8vo,	3 00
Gerhard's Sanitary House Inspection	Square 16mo,	1 00
Mott's The Air We Breathe, and Ventilation	16mo,	1 00
Reid's Ventilation of American Dwellings	12mo,	1 50
Wilson's Mine Ventilation	16mo,	1 25

MISCELLANEOUS PUBLICATIONS.

Alcott's Gems, Sentiment, Language	Gilt edges,	5 00
Bailey's The New Tale of a Tub	8vo,	75
Ballard's Solution of the Pyramid Problem	8vo,	1 50
Barnard's The Metrological System of the Great Pyramid.	8vo,	1 50
Davis's Elements of Law	8vo,	2 00

Emmon's Geological Guide-book of the Rocky Mountains	8vo,	$1 50
Ferrel's Treatise on the Winds	8vo,	4 00
Haines's Addresses Delivered before the Am. Ry. Assn.	12mo.	2 50
Mott's The Fallacy of the Present Theory of Sound	Sq. 16mo,	1 00
Perkins's Cornell University	Oblong 4to,	1 50
Ricketts's History of Rensselaer Polytechnic Institute	8vo,	3 00
Rotherham's The New Testament Critically Emphasized.	12mo,	1 50
" The Emphasized New Test. A new translation.	Large 8vo,	2 00
Totten's An Important Question in Metrology	8vo,	2 50
Whitehouse's Lake Mœris	Paper,	25
* Wiley's Yosemite, Alaska, and Yellowstone	4to,	3 00

HEBREW AND CHALDEE TEXT-BOOKS.

For Schools and Theological Seminaries.

Gesenius's Hebrew and Chaldee Lexicon to Old Testament. (Tregelles.)	Small 4to, half morocco,	5 00
Green's Elementary Hebrew Grammar	12mo,	1 25
" Grammar of the Hebrew Language (New Edition)	8vo,	3 00
" Hebrew Chrestomathy	8vo,	2 00
Letteris's Hebrew Bible (Massoretic Notes in English).	8vo, arabesque,	2 25

MEDICAL.

Bull's Maternal Management in Health and Disease	12mo,	1 00
Hammarsten's Physiological Chemistry. (Mandel.)	8vo,	4 00
Mott's Composition, Digestibility, and Nutritive Value of Food.	Large mounted chart,	1 25
Ruddiman's Incompatibilities in Prescriptions	8vo,	2 00
Steel's Treatise on the Diseases of the Ox	8vo,	6 00
" Treatise on the Diseases of the Dog	8vo,	3 50
Woodhull's Military Hygiene	16mo,	1 50
Worcester's Small Hospitals—Establishment and Maintenance, including Atkinson's Suggestions for Hospital Architecture	12mo,	1 25

549 .D167t 1899 C.1
A text-book of mineralogy,
Stanford University Libraries
3 6105 032 423 019

Branner Earth Sciences Library ✓

DATE DUE

STANFORD UNIVERSITY LIBRARIES
STANFORD, CALIFORNIA 94305-6004